AD NUMBER

AD813281

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; 16 JAN 1967. Other requests shall be referred to Redstone Scientific Information Center, Attn: Research Branch. Redstone Arsenal, AL 35809.

AUTHORITY

NASA TR Server website

AD

RSIC-611

SPACE VEHICLE NAVIGATION, GUIDANCE, AND CONTROL

by

R. Langston

January 1967

[redacted]

REDSTONE SCIENTIFIC INFORMATION CENTER

REDSTONE ARSENAL, ALABAMA

JOINTLY SUPPORTED BY

U.S. ARMY MISSILE COMMAND

GEORGE C. MARSHALL SPACE FLIGHT CENTER

DISPOSITION INSTRUCTIONS

Destroy this report when it is no longer needed. Do not return it to the originator.

DISCLAIMER

The findings in this report are not to be construed as an official Department of the Army position.

16 January 1967 RSIC-611

SPACE VEHICLE NAVIGATION, GUIDANCE, AND CONTROL

by

R. Langston

[redacted]

Research Branch
Redstone Scientific Information Center
Research and Development Directorate
U. S. Army Missile Command
Redstone Arsenal, Alabama 35809

ABSTRACT

This report contains a summary of space vehicle guidance and control plus an extensive bibliography of the subject area. This report is intended to encompass only the interplanetary portion of the space vehicle flight. Launch vehicle guidance and control is covered in RSIC-494, entitled "Methods of Launch Vehicle Control." However, some fringe information in the area of orbital flight is included in the bibliography which may be applicable to interplanetary flight.

FOREWORD

This summary of space vehicle guidance and control is divided in two main parts. The first part consists of narrative summary and analysis based on a review of pertinent literature in the subject field, while the second part consists of a bibliography of 1246 references in the subject field. The bibliography is divided into four sections. Four of the subject categories are included in both the Interplanetary (or Lunar) Flight Section and the Orbital Flight Section. The remaining two subject categories comprise the other two sections. In each section, the entries are grouped by subject category and arranged alphabetically by corporate author or personal author. An author index is provided.

This survey was conducted utilizing the following sources of information:

1) RSIC Documents Holdings.
2) Defense Documentation Center Computerized Search.
3) NASA Computerized Search.
4) NASA STARS and CSTARS.
5) Science Abstracts: Section B. Electrical Engineering.
6) Applied Science and Technology Index.
7) Engineering Index.
8) International Aerospace Abstracts.

The time period covered by this survey was from January 1961 through March 1966.

CONTENTS

ILLUSTRATIONS

INTRODUCTION

This report contains a general summary plus a detailed bibliography on Space Vehicle Guidance, Navigation, and Attitude Control. The report is intended as a general reference source for further research in various areas of Space Vehicle Guidance and Control. Only a general summarization is provided since a detailed analysis of all areas in this vast field would be unreasonable in terms of time and costs. Launch vehicle guidance and control is presented in RSIC-494, entitled "Methods of Launch Vehicle Control."

For the purposes of this report, space vehicle guidance and control is the consideration of guidance and control concepts beyond Earth orbital flight operations which includes both lunar and interplanetary flight. However, certain fringe information is presented in the bibliography on orbital operations which may have application in lunar or interplanetary flight. It is also realized that the problems of lunar versus interplanetary flight are somewhat different since, during lunar flight, the vehicle is under the influence of the Earth's or the moon's gravitational influence for the major portion of the flight (the influence of the sun's attraction is greater than the Earth's or moon's attraction for only a minute portion of the flight). During interplanetary flight, the influence of the Earth and moon becomes negligible and the attraction of other bodies is very small depending upon, of course, the proximity of the vehicle to other large bodies.

For the purpose of clarity in this report, space navigation is defined as the methods and/or equipment used to determine the position and velocity of the vehicle in space. Space vehicle guidance is defined as the methods and/or equipment used to determine the commands to be sent to the control system to maintain the vehicle on its flight path or course. The guidance system will process the navigation data and compute the commands necessary to maintain the vehicle on the desired trajectory.

Space vehicle control is defined as the methods and/or equipment used for correlating the command signals received from the guidance system with the signals received from its attitude stabilization sensors to compute and command actuation of the thrust vector control mechanism.

The author has intended, for purposes of simplicity and clarity, to provide as much separation in the functions of guidance, navigation, and control as possible consistent with standard practice in use of the terms.

GUIDANCE OF INTERPLANETARY VEHICLES

The space vehicle guidance, which determines the flight path for the vehicle, issues commands to the control system which, after adding its own signals to provide attitude stabilization, actuates the thrust and/or thrust vector control mechanism to alter flight direction or velocity. The space vehicle guidance system will usually consist of an inertial package, a guidance computer, and signal processing circuitry.

The inertial package (consisting essentially of gyros to sense motion in the pitch, yaw, or roll planes and accelerometers to measure forces on the pitch, yaw, or roll axes) is alined to an Earth-fixed or a space-fixed reference prior to launching. The inertial package, since it measures external disturbances to the vehicle in flight and causes the guidance system to issue commands to correct for these disturbances, tends to maintain the vehicle on a prescribed trajectory in its original frame of reference. However, because of the immense distances involved in interplanetary flight, very small drift errors (caused by bearing friction in the gyros, etc.) in the inertial package will necessitate the use of a vehicle-borne or Earth-fixed navigation system to periodically correct for these errors.

The guidance computer, whether it is vehicle-borne or ground-based, compares the data received from the inertial package and the navigation system with the data programmed into the computer for a standard trajectory to compute the guidance commands to be issued so as to aline the actual trajectory to the standard trajectory.

The guidance system for an interplanetary vehicle must be very accurate, optimized in its techniques, and somewhat flexible in its operation. The accuracy is necessary to preclude small angle errors initially from causing gross distance errors over the large distances traveled. Optimization of the guidance system is necessary to prevent unwarranted expenditure of fuel which will be required later. The guidance system must also be somewhat flexible in its operation since there are certain inaccuracies in measurement of the distances to the planets (from the Earth) and there are some unknown and/or unpredictable forces which can act on the vehicle.

Dr. Pickering[1] believes that guidance system designers need to avoid a priori thinking conditioned by previous developments in this field and look for the simplest workable systems. The guided missile art has developed a folklore about performing all guidance operations without using a man and, considering the military problem at present,

this makes a lot of sense. However, it does not mean that future guidance of missiles or space vehicles should a priori be made unmanned. Self-contained guidance systems have been fostered by the huge success of inertial guidance systems in recent years. Militarily, the self-guided missile is the answer to many problems - greater accuracy, more reliability, willingness to attack any target, and obvious immunity of the missile to all but direct countermeasures. However, self-contained guidance systems are not the only answer, since several good systems operate on the principle that sensors and computers can be distantly located and information relayed to the missile by radio. The solution to the guidance problem should not be hindered by assuming that either self-contained or ground-based systems must be used.

Table I indicates man's ability to perform computer functions relative to the ability of a machine. Dr. Pickering points out that the limitations of man in solving guidance problems are response time and accuracy and that if a guidance problem requires a reaction time of a tenth of a second or less or if the problem requires very accurate and rapid evaluation, it could easily be beyond the capability of the human mind. Further, the problem of how to use man in the guidance loop needs much more exploration. Because of man's versatility and flexibility, he may be a very valuable adjunct to the guidance loop.

Table I. Man Versus Machine's Ability to Perform Computer Functions

	Input-Output Rate	Speed and Accuracy of Computation	Information Storage	Versatility and Flexibility
Man	Poor	Poor	Poor	Good
Machine	Good	Good	Good	Poor

There exist two different design philosophies for space navigation and guidance systems. These two design philosophies in space navigation and guidance are a logical evolution of two previous design philosophies used in missile systems. One design concept[2] is fostered by Dr. Draper of the Massachusetts Institute of Technology's Instrumentation Laboratory. The second design concept is fostered by Dr. Haeusermann of Marshall Space Flight Center's Astrionics Laboratory.

Massachusetts Institude of Technology guidance design philosophy is to store the precomputed requirements of a series of optimum

trajectories in the onboard guidance computer memory so that a minimum of computation is performed on board. The function of the onboard guidance system, in this instance, is to continuously compare the vehicle flight path to the trajectory or the closest of a family of trajectories and to make momentary corrections to return the vehicle to its standard trajectory. This guidance concept may utilize either the "delta minimum" or the "Q-Matrix" guidance modes. This guidance concept has the advantages of simplicity, low cost, and design change flexibility.

Marshall Space Flight Center guidance design philosophy[2] is to store only the formulas for computing a new optimum trajectory from moment-to-moment in the onboard guidance computer memory. In this "explicit" or path adaptive guidance concept, only the polynomials are precomputed to enable the onboard guidance computer to solve the guidance equations for an optimum trajectory. This will necessitate many logic circuits in the onboard computer. Perhaps the major advantage of this guidance concept is its operational flexibility in that it can adapt the vehicle flight path to the optimum trajectory despite wide changes in thrust level, changes in direction, or unknown factors in the distances or directions encountered. Recent advances in the state-of-the-art of microcircuits may serve to offset considerably the disadvantages of weight and cost of this guidance concept.

In October 1961, Gates et al[3] presented a paper on the state-of-the-art of post injection guidance for unmanned lunar and planetary spacecraft. The paper states that the launch vehicle, using a ballistic missile guidance system, cannot deliver a spacecraft to its destination with sufficient accuracy. Also, without post injection guidance, the vehicle would not be able reliably to hit the moon or the near planets. A small midcourse correction after injection, requiring propellant of only one or two percent of the spacecraft weight, can considerably reduce the moon or planetary miss distance. They state that Earth-based radio midcourse guidance will be accurate enough for most of the missions to the moon and close planets. However, some form of onboard celestial navigation will probably be required for missions to Jupiter, Saturn, and beyond.

An onboard approach guidance system, which initially operates at one to two million miles from the planet (to 100,000 miles from the planet) and utilizes as inputs the angles measured between the target planet and celestial bodies, can reduce the miss distance error from a few thousand miles to a few tens or hundreds of miles.[3] As can be seen by Table II, which provides miss distance using only Earth-based midcourse guidance, some type of planetary approach guidance is necessary to reduce the dispersion.

Table II. Miss Distance Resulting From Earth-Based Radio Midcourse Guidance*

Target	(1) Miss Due to Representative Injection Guidance (km)	(2) Assumed Tracking Accuracy	(3) Orbit Determination Accuracy from (2), (km)	(4) Midcourse Maneuver to Correct (1) (meters/sec)	(5) Accuracy of Maneuver (Assumed) Pointing (deg)	Magnitude (%)	(6) Error Due to Maneuver (km)	(7) Total Accuracy (Root Mean Square of 3 and 6) (km)
Moon	6000	2×10^{-5} radians 0.15 meter/second	10	40	½	1	64	65
Mars	500,000	2×10^{-5} radians 0.15 meter/second	2500	20	½	1	5400	6000
Venus	300,000	2×10^{-5} radians 0.15 meter/second	1000	20	½	1	2700	2900

*All quantities are one-sigma

Lally[4] proposes an optical mosaic guidance concept for interplanetary flights. He considers the difficulty with inertial systems on these flights as (1) gyro drift errors over long distances, (2) inertial platform problems created by rotating spacecraft to simulate gravity in manned mission, and (3) loss of continuity in inertial guidance caused by unforeseen mission requirements or a breakdown of the attitude control system. He states the difficulty in celestial-inertial systems would involve the formidable task of star tracking while the spacecraft is rotating (to simulate gravity). A block diagram of the mosaic guidance system is provided in Figure 1.

The system relies upon an onboard computer and detectors sensitive to stellar and planetary stimuli. The detectors are composed of numerous sub-detectors resembling a mosaic. Strapped- down mosaic detectors are systematically mounted on the spacecraft, thus relying on the structural integrity of the spacecraft rather than translation of data according to gimbal movement.

Supplementary guidance equipment (to mosaic guidance) will be necessary for corrective maneuvers, planetary soft landings, rendezvous maneuvers, and reentry.

The mosaic system will establish spacecraft position and velocity by detection of a planet, a satellite, an asteroid, and/or stars. Also, since stars differ greatly in their color, temperatures and sub-detectors can be built to respond to specific spectral bands, then an additional tool is provided to fix the craft's position in space.

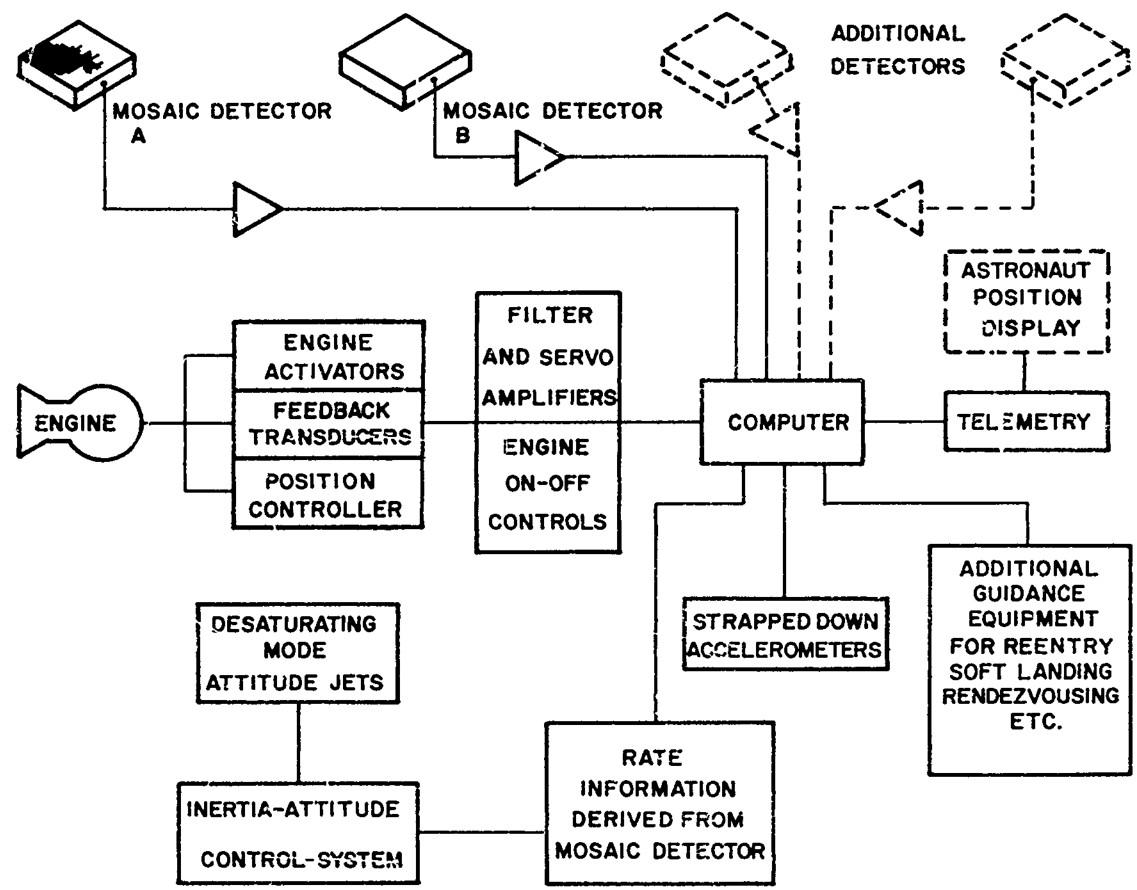

Figure 1. Mosaic Guidance in a Spacecraft System[4]

Alonso and Hopkins[5] describe the onboard Apollo guidance computer as a digital computer. The computer is a binary, 15 digit (or bit) general purpose computer using parallel word transfer and single address instructions. Instructions and data are stored in a memory consisting of several thousand words of fixed memory, wired-in memory, and about one-thousand words of erasable memory (the erasable memory includes a few addressable central registers). The logic of the computer consists of three-input "nor gates" of the microcircuit type. Erasable memory selection is performed with core-transistor circuits, and current drivers for fixed and erasable memories are diode-transistor circuits.

Hakes[6] presented the results of a study of guidance and navigation systems for lunar missions in October 1961. He states that the guidance systems which have been used for space probes and those which were currently planned (in October 1961) for other programs have taken advantage of current state-of-the-art in systems and the use of off-the-shelf hardware. This has generally resulted in a heterogeneous system consisting of independent launch and injection systems, in some cases separate for each boost vehicle stage; radio-controlled midcourse guidance with ground-based computation; and a variety of combination radio-optical-inertial systems for operation in the moon's vicinity. The study considers the self-contained systems on board the vehicle as a primary mode of guidance and navigation and Earth-based systems as a secondary or backup mode of guidance and navigation. The guidance and navigation requirements for each phase in the vehicle's trajectory and a guidance and navigation system to satisfy these requirements are discussed.

An integrated guidance and navigation system containing an astro-inertial platform with a two-startracker, wide-angle and narrow-angle optical Earth and moon trackers, an integrated computer-clock, and a radio altimeter are described. The use of the man for monitoring functions, for decision making, and for emergency operations was considered in this study.

As a result of the study,[6] it was concluded that an integrated, self-contained guidance and navigation system capable of satisfying the lunar mission requirements could be operational in the 1965 to 1970 period. The total primary system would occupy three to four cubic feet, would weigh under 200 pounds, and would use approximately one-half kilowatt of power.

NAVIGATION FOR INTERPLANETARY FLIGHT

Space navigation, the determination of a vehicle's position and velocity in space, can be accomplished by either onboard or ground-based navigation equipment or a combination of both ground and air-borne equipment. The ground-based navigation system may consist of several tracking stations located at various positions around the surface of the Earth and a centralized computer which receives data from these tracking stations and calculates position and velocity of the space vehicle. The space vehicle-borne navigation equipment may consist of:

1) Startrackers[1] to determine the position in space of the vehicle.
2) Horizon detectors[2] or bubble level detector (if vehicle is well within strong gravitational force field of the Earth or another planet) for establishing a local vertical for the vehicle.
3) A radar to determine altitude and position relative to the planetary body on which the vehicle will attempt to orbit or land.

Either monopulse or continuous wave (CW) doppler radar may be used for the ground or vehicle-borne radar trackers, the only difference being that relative velocity (of the tracker to the item being tracked) using the monopulse radar is computed from the transit times of successive radar returns whereas the relative velocity using the doppler radar is computed from the difference in frequency of the return wave from the transmitted wave.

Another general method of navigation would be to use a system of satellites. Each satellite would be in a certain position relative to the Earth at a certain point in time and would emit a beacon on a certain frequency. The space vehicle could determine its position relative to several of these satellites and this position could be resolved back to an Earth-fixed reference.

The use of vehicle-borne celestial navigation techniques (such as the use of startrackers and horizon scanners) appear to be more favorable for interplanetary flight because of:

1) The time delay for Earth-acquired navigation data to be transmitted over long distances.
2) The refraction and propagation velocity errors encountered in Earth tracking stations operating over such extreme ranges.
3) The high power and weight requirements for an onboard radar to navigate interplanetary distances.

However, the use of a smaller onboard radar tracker may be quite advantageous when the vehicle is approaching a planet and preparing either to orbit or land on the planet.

The startracker may consist of a telescope manually centered on a star whereby error signals are fed back by the telescope gimbaling mechanism or with a scanning disk rotating in front of a photoelectric cell. Position errors are found by noting the quadrant the star image falls within on the photoelectric cell. This position fix is related back to the relative positions of other planets by a clock contained in the vehicle.

The horizon scanner or infrared detector determines a local vertical for the vehicle by scanning the sun's or a planet's surface and locating the body's horizon on both sides because of the great difference in temperature of a body and free space.

A factor common to the various methods of celestial navigation is that the angles between at least two stars and two bodies of the solar system must be measured very accurately.[3] Spacecraft velocity can be determined by two such position fixes made as widely separated as maneuver fuel economy permits. Several celestial navigation methods are shown in Figure 2.

Northrop's Nortronics Division which is performing Stellar Inertial Navigation System (STINGS) work, has developed a single star sensing system[2] capable of acquiring two star sights in rapid sequence. This system, if used in conjunction with an accurate vertical reference for near Earth orbits or with a solar or planetary sight on interplanetary trajectories, would be capable of highly accurate onboard position determination.

The National Aeronautics and Space Administration sponsored Early Manned Planetary-Interplanetary Roundtrip Expeditions (EMPIRE) trajectory studies and Unfavorable Manned Planetary-Interplanetary Roundtrip Expeditions (UMPIRE) trajectory studies, although not primarily concerned with guidance and navigation, treated the problem in sufficient depth to establish the need for a navigation system employing startracking data smoothed by an inertial platform. The studies suggest that ground tracking and communications networks may become backup for the onboard systems for the essential reason that communications failure must not eliminate the return chances of a manned spacecraft.

An estimate[2] of the relative accuracy of the basic navigation sensors is given in Table III.

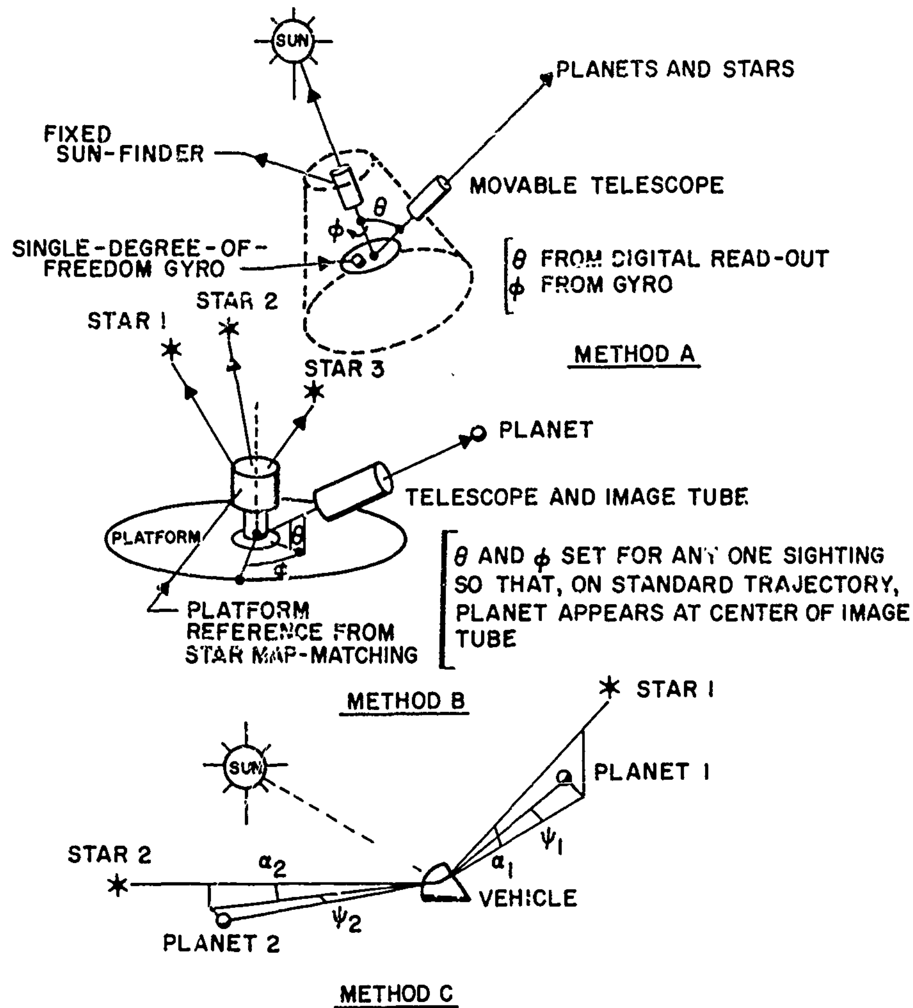

Figure 2. Celestial Navigation Methods

Kochi and Dibble[7] conducted a survey of sensing and mechanization computation techniques for solving the midcourse navigation-guidance problem on board the spacecraft. The sensing techniques emphasized in this survey include only optical-inertial systems, since the authors believe these systems appear to typify the self-contained concept for manned deep space applications. The specific areas covered in this survey were the data gathering, computation, and data processing techniques for handling the attitude determination, trajectory determination, and trajectory control computation problems.

A generalized block-diagram of the major subsystems of a space vehicle midcourse navigation-guidance system is given in Figure 3.

Table III. Relative Improvements Anticipated in Sensor Accuracy[2]

	Estimate of Basic Sensor Capability		
	Operational 1965	Operational 1970	Operational 1975
Startracker	20 arc sec per axis	10 arc sec per axis	7 arc sec per axis
IR Horizon Sensor	6 arc min per axis	2 arc min per axis	1 arc min per axis
(Additive errors both for instruments and phenomenology at 200 nm)			
Velocity/Height Sensors	-	0.1 percent	0.05 percent
Optical Correlator	-	1.0 milliradian	0.7 milliradian
Radio Altimeters	100 ft	75 ft	50 ft
Gyros	0.1 deg per hr	0.03 deg per hr	0.01 deg per hr
(30-day random stability for 1-lb gyro)			
Gravity-Gradient Accelerometers	-	1 deg	0.25 deg
(for low-altitude orbits)			
Planetary Body Tracker	-	5 arc sec	1 arc sec
(In relative centerline position for distant ranges)			

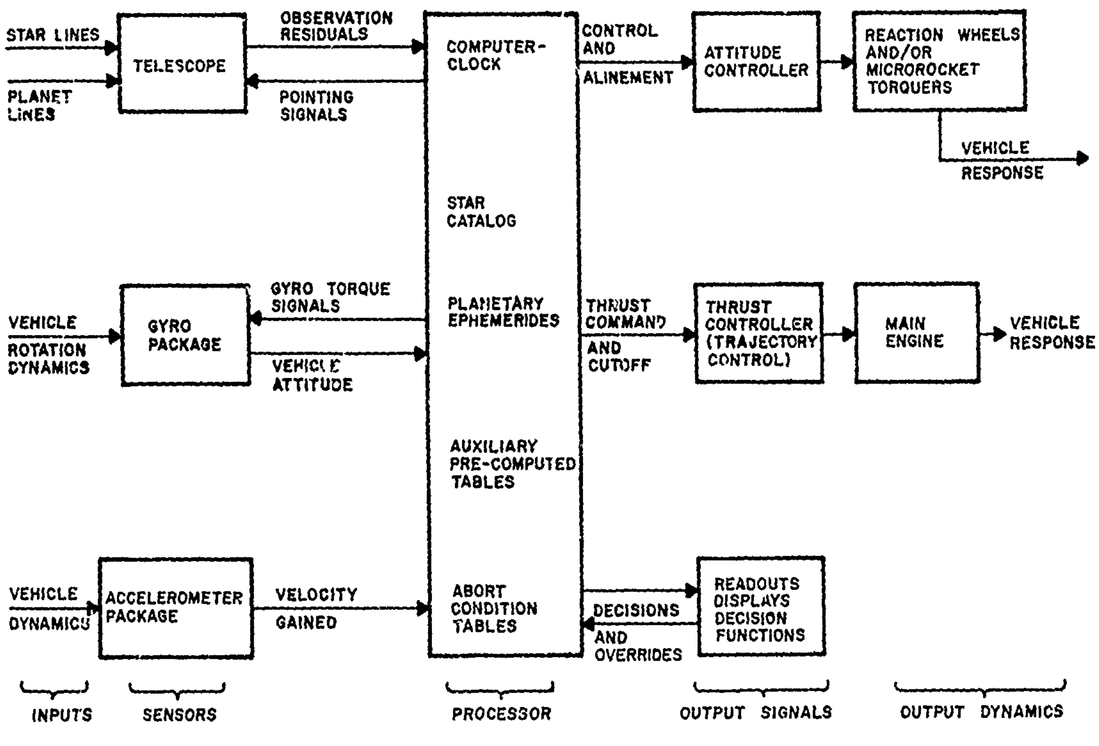

Figure 3. Major Subsystems of Midcourse Navigation-Guidance System

The midcourse navigation-guidance computations can be divided into two categories. The first computation category consists of all auxiliary computation functions associated with the specific systems concept employed and depends upon the particular sensors used in the system. Table IV summarizes the characteristics of some of the integrated midcourse navigation-guidance concepts covered by Kochi and Dibble.[7]

The second computation category covers computation techniques associated with the processor element for handling the actual solution of the navigation-guidance problem, and this category is independent of the specific mechanization of the sensor elements. Computation loads in this category can be discussed primarily in terms of representation. That is, the specific technique utilized to represent the reference trajectory, the transition matrices, the data process filter, and the guidance law primarily define the major part of the computation load for this category. A summary of the computation load characteristics for the various representation techniques is given in Table V.

Woestemeyer[8] considers the use of an onboard TV camera system to supplement National Aeronautics and Space Administration DSIF tracking network in providing approach phase navigation for a planetary orbiting or landing. Earth-based trajectory computation is assumed. It is expected that, using this TV camera system, improvements can be made in trajectory prediction and navigation accuracy. An accuracy of ±1 milliradian is adequate in determining the planet's position relative to the stars. Analysis indicates that an Image Orthicon camera is capable of this required accuracy. Tests indicate that it can register the positions of stars to the fourth magnitude, and possibly the sixth magnitude, in the same frame with Mars or Venus, and without sophisticated techniques. Special circuits have been found which indicate coverage of the necessary range without attenuation of the planet image.

Data rate requirements (in using a TV sensor) are high if the raw video must be transmitted to the Earth. However, data compression techniques have been found that can reduce the number of transmitted bits by two or three orders of magnitude.

Goldberg and Burrows[9] propose a solid-state doppler radar design to provide accurate navigational inputs for both planetary landings and space rendezvous missions. The functionally integrated radar weighs 34 pounds and uses the same antenna, transmitter, range, and velocity circuits for both missions. A 50 percent duty-cycle, variable-PRF modulation system is utilized. Characteristics of each mode of operation are as follows:[9]

Table IV. Summary of Characteri

Integrated Midcourse Systems Concepts	Observables for Trajectory Determination	Attitude Determination, Alinement, and Control	Thrust Vector	
Single-Gimbaled Telescope Strapdown Accelerometer Package	Gimbal drive angles on near points (e.g. alt. azimuth) Two independent observables	Telescope drive angles for stellar sightings Alinement computational and needs to be precision Control - stellar error signals	Use rough alinement with sun and planet seekers Vectoring complex Metering simple, use one accelerometer	A c r I c T t
Gimbaled Sextant Strapdown Accelerometer Package	Separation angle of near point with stellar line One observable per observation	Gimbal angles of sextant on stellar sightings Alinement is computational and does not need to be precision Control - gimbal angle error signal on stellar sightings	Use rough alinement with sun and planet seekers Vectoring complex Metering simple, use one accelerometer	A p r I c T c
Three-Gimbaled Telescope Strapdown Accelerometer Package	Telescope drive angles on near point Two observables per observation	Telescope gimbal angle readouts on stellar sightings Alinement is computational and needs to be precision Control - stellar line error signals	Use telescope drive angles Vectoring complex Metering simple, use one accelerometer	A p r I c T c
Gimbaled Sextant Strapdown Gyro Package Strapdown Accelerometer Package	Separation angle on near point and stellar line One observable per observation	Gimbal angle readouts on stellar lines Fine alinement mode computation to initialize direction cosine equations Control - gyro error signals	Use direction cosine equation Vectoring complex Metering simple, use one accelerometer	A p r I c T t
Body Gimbaled Telescope Strapdown Gyro Package Strapdown Accelerometer Package	Telescope drive angles on near point Two observables per observation	Telescope gimbal angle readouts on stellar lines Fine alinement mode computation to initialize direction cosine equations Attitude control - gyro error signals	Use direction cosine equations Metering simple, use one accelerometer	A p b I c T c
Gimbaled Sextant Gimbaled Inertial Platform With Gyro and Accelerometer Packages (MIT System)	Separation angle of near point with stellar line One observable per observation	Sextant gimbal angle readouts on stellar lines Fine alinement mode computation to fine aline platform Attitude control - platform gimbal angle error signals	Use platform gimbal readouts Vectoring simple Metering complex, use three accelerometers	A p r I c T s
Platform-Mounted Telescope Gimbaled Inertial Platform With Gyro and Accelerometer Package	Telescope gimbal angles with respect to platform (celestial) axes Two observables per observation	Telescope gimbal angle readouts or telescope field error signals on stellar lines (attitude control) Continuous stellar monitor for fine alinement of platform	Use platform gimbal readouts Vectoring simple Metering complex, use three accelerometers	A p t I s T s

hmary of Characteristics of Integrated Midcourse Navigation-Guidance Concepts

Thrust Vector	System Computational Functions Required	Other Comments	Summary of Ess Desirable Characteristics
ough alinement with nd planet seekers ring complex ing simple, use one erometer	Attitude data process computation complex and must be precision Pointing computations complex Thrust vectoring computation complex	Observation resolution poor Difficult to update attitude information Attitude determination poor No attitude hold while observing Attitude knowledge must be precision	Minimal hardware
ough alinement with nd planet seekers ring complex ing simple, use one erometer	Attitude data process computation complex but need not be precision Pointing computation complex Thrust vector computation complex	Observation potentially high precision Difficult to update attitude information Attitude determination can be accurate No attitude hold while observing Attitude knowledge need not be precision	Minimal hardware No precision attitude
lescope drive ring complex ing simple, use one rometer	Attitude data process computation very complex and must be precision Pointing computation complex Thrust vector computation complex	Observables high precision Difficult to update attitude information Attitude determination is accurate Continuous stellar attitude hold while observing Attitude knowledge must be precision	Moderate accuracy (high accurac no transients) High precision attitude while data gathering
rection cosine on ing complex ing simple, use one rometer	Attitude data process computation complex but need not be precision Pointing computation complex Thrust vector computation complex	Observables high precision but subject to transients Update attitude by integration of direction cosine equations Continuous gyro attitude hold while observing Attitude alinement need not be precision Discrete stellar monitor of gyro package	Moderate accuracy (high accurac no transients) No precision attitude Ideal for ESG packages
rection cosine ons ng simple, use one rometer	Attitude data process computation complex and must be precision Pointing computation complex Thrust vector computation complex	Observables high precision but subject to transients Update attitude by integration of direction cosine equations Continuous gyro attitude hold while observing Attitude alinement must be precision Discrete stellar monitor of gyro package	Moderate accuracy (high accuracy no transients) Hardware moderately simple Ideal for the ESG packages
tform gimbal read- ng simple g complex, use ccelerometers	Attitude data process computation complex but need not be precision Pointing computation complex Thrust vector computation simple	Observables high precision but subject to transients No update attitude computation Continuous attitude from platform gimbals Continuous gyro attitude hold while observing Attitude alinement need not be precision Discrete stellar monitor of gyro package	Moderate accuracy (high accuracy no transients) Hardware moderately simple Can aline in celestial reference
tform gimbal read- ng simple g complex, use ccelerometers	Attitude data process computation simple and must be precision Pointing computation simple Thrust vector computation simple	Observables high precision No update attitude computation Continuous attitude from platform gimbals Continuous gyro attitude hold while observing Attitude alinement	High accuracy Versatile Data process relatively simple Telescope pointing computation ... Attitude computations and alineme simple Can aline to celestial reference

vigation-Guidance Concepts

Other Comments	Summary of Essential Desirable and Undesirable Characteristics	
	Desirable Characteristics	Undesirable Characteristics
n resolution poor update attitude information ermination poor hold while observing wledge must be precision	Minimal hardware	Low accuracy Precision attitude is required Computations maximal Subject to transients Update attitude depends on stellar fixes
potentially high precision update attitude information ermination can be accurate hold while observing wledge need not be precision	Minimal hardware No precision attitude	Low accuracy Subject to transient loadings Computations maximal Update attitude depends on stellar fixes
high precision update attitude information rmination is accurate stellar attitude hold while wledge must be precision	Moderate accuracy (high accuracy if no transients) High precision attitude while data gathering	Complex hardware and data processing Computations maximal Precision attitude Attitude computations complex
high precision but subject ude by integration of direction ions gyro attitude hold while observing ement need not be precision llar monitor of gyro package	Moderate accuracy (high accuracy if no transients) No precision attitude Ideal for ESG packages	Complex hardware and data processing Integration of direction cosine equations Attitude computations and initial alinement complex
high precision but subject ude by integration of direction ions gyro attitude hold while observing ement must be precision llar monitor of gyro package	Moderate accuracy (high accuracy if no transients) Hardware moderately simple Ideal for the ESG packages	Complex hardware and data processing Requires high precision attitude Integration of direction cosine equations Attitude and initial alinement complex
high precision but subject titude computation ttitude from platform gimbals yro attitude hold while observing ement need not be precision llar monitor of gyro package	Moderate accuracy (high accuracy if no transients) Hardware moderately simple Can aline in celestial reference	Complex hardware and data processing Integration of direction cosine equations Attitude and initial alinement complex
high precision titude computation ttitude from platform gimbals yro attitude hold while ement	High accuracy Versatile Data process relatively simple Telescope pointing computation simple Attitude computations and alinement simple Can aline to celestial reference	Hardware complex Gimbal occlusion High precision platform alinement and monitor

Table V. Computation Loads Summary r Representation Theories

Representation Theory	Computation Load	Memory Load	Comments	
			Advantages	Disadvantages
Numerical Integration of Equations of Motion	Large Moderately complex logic	Essentially none, if initialized from ground Moderate if initialized from decision points Store trajectory parameters at decision points	Versatile Can handle abort easily Can be made very accurate	Complex integration for each data point Complex channeling logic Accumulation of roundoff and truncation
Tabular Interpolation - Extrapolation	Moderate - mostly channeling logic Simple logic	Very large Tabular store trajectory parameters and transition matrices Abort conditions require additional, large banks	Simple mechanization Can be very accurate over prediction time	Approximate Good for short prediction times or "flat" trajectories Frequent reinitialization
Analytic Two-Body Integrals	Large logic Complex logic	Moderate if initialized from decision points Store trajectory parameters at decision points	Good for fixed memory computer Versatile Result computed directly for each data point	Complex logic Requires "patching" computation Approximate Logic must be changed for different logics
Analytic Truncated Power Series on Two-Body Integrals	Large Complex Simpler logic than above analytic method	Moderate if initialized from decision points Store trajectory parameters at decision	Good for fixed memory computer Result computed directly for each data point Simpler logic than closed-form case	Complex logic Requires "patching" computation Approximate Good only for short prediction times and "flat" trajectories

Radar Characteristics - Landing Mode Operation

Altitude Range	0 ft to 20 miles
Altitude Accuracy	±1% ±2 ft
Velocity Range	±6000 fps
Velocity Resolution	±½ fps
Velocity Accuracy (V_x, V_y, V_z)	±0.2% $\lvert V \rvert$ ±½ fps

$\lvert V \rvert$ = magnitude total velocity vector

Radar Characteristics - Rendezvous-Mode Operation

Range	0 to 250 miles (cooperative) 0 to 12 miles (noncooperative)
Range Accuracy	±2 ft ±½%
Relative Velocity	±6000 fps
Velocity Accuracy	±½ fps
Velocity Resolution	±½ fps
Angle Accuracy	±2 milliradians

The total power required for this radar is 84 watts (includes 24 watts maximum for antenna drive power).

Navigation data processing techniques occupy a key role in the successful mission of a space vehicle. For example, the accuracy of the navigational data and its timely implementation will depend on the data processing technique chosen as well as being dependent on the inherent accuracies of the navigation sensors. However, another very important consideration is that the processing technique chosen does not entail such unwarranted accuracy and/or computation complexity that it requires a much larger, costlier computer on board the space vehicle than is really necessary.

Navigation data processing techniques which may be utilized during low-thrust interplanetary operations include the method of differential corrections, optimum linear estimation theory, maximum likelihood method, and the optimum filter theory.

The method of differential corrections, the classical method of the astronomer, is cumbersome for large amounts of observational measurements and is not well suited for implementation into a vehicle-borne

computer.[10] The statistical method of the optimum linear estimation theory seems to have the greatest promise. The method of maximum likelihood, which is based on the premise of maximizing a specific conditional probability, has received considerable attention. The optimum filter theory, whose purpose is to find a linear estimator that minimizes some function of the variances and covariances of the uncertainties in the estimated state vector, provides an alternate method. One study[10] has shown that all of these data processing techniques lead to equivalent results if the measurement uncertainties have Gaussian distributions.

ATTITUDE STABILIZATION (CONTROL) OF INTERPLANETARY VEHICLES

The space vehicle control system actuates the thrust control and/or thrust vector control mechanism based on guidance command and attitude stabilization signals. The control system contains rate gyros and accelerometers which sense the short-term instabilities or attitude deviations in the vehicle and a control computer which calculates the control correction signals based on these error measurements.

In interplanetary flight, the vehicle must be attitude stabilized to some reference such as the sun and the stars so as to permit the celestial navigation system to function and to permit the solar cells to face the sun and provide power for the craft. The forces which may act on the vehicle to necessitate attitude stabilization include:

1) Gravitation effects from the sun, Earth, and other bodies.
2) Magnetic and electric fields.
3) Cosmic radiation pressure.
4) Any motion within the spacecraft.

Attitude stabilization techniques include aerodynamic stabilization, spin stabilization, gravity stabilization, radiation pressure stabilization, auxiliary rocket or cold gas jet stabilization, flywheel stabilization, and magnetic field stabilization.

Aerodynamic stabilization, of course, can only be used in low Earth or planetary orbits where the geometry of the vehicle reacts with atmospheric force to stabilize the vehicle. Spin stabilization is usually accomplished by designing the spacecraft so that most of the weight is concentrated at the outer rim, thereby providing a moment of inertia about its axis. Gravity stabilization, caused by attraction from the Earth or other planets, is effected by designing the craft long and slender. The length of the craft will tend to remain normal to the body of attraction because of the difference in gravitation forces on the nose of the craft from the aft end of the craft. Radiation pressure stabilization may use reflectors on the spacecraft to stabilize the craft at a certain attitude with respect to the sun (this stabilization device could only be employed in interplanetary space where the gravitational effects of the Earth or other bodies were negligible).

Auxiliary rockets or cold gas jets can be effectively used on a spacecraft to provide stabilization. A rocket could be fired or a gas jet could be opened at any time to effect stabilization. However, because of weight and fuel limitations aboard the craft, this stabilization

technique should perhaps be combined with some other method to stabilize the craft.

Flywheels or torque wheels may provide a very effective means of stabilizing interplanetary spacecraft. The flywheel operates at a constant speed and tends to oppose any sudden changes in the craft's attitude since the flywheel produces torques to oppose any external torques on the vehicle.

Magnetic field stabilization can be effected by use of the Earth's or another planet's magnetic field which will induce eddy currents in the stabilization device which will oppose the original magnetic field. The stabilization device may be a permanent magnet, a torquing coil, or a reaction sphere.

The attitude control system for an interplanetary craft must furnish a relatively constant, low-level torque or force during the entire flight.[3] One of the primary external disturbing forces on the interplanetary craft is solar radiation pressure. Most attitude control studies for satellites show that the optimum system is provided by a momentum exchange device such as reaction wheels, a reaction sphere, or torqued gyros which are periodically reset by mass-expulsion jets. For lunar and interplanetary flight, however, control of the effects of solar radiation pressure by means of a momentum-exchange device does not appear to be satisfactory because of its low torque or acceleration capability resulting in a long system time constant. The results of a trade-off study[3] comparing two methods of attitude control (mass expulsion versus momentum exchange) on a weight basis showed that a mass-expulsion system using cold nitrogen had a 10 to 1 weight advantage over a momentum exchange system utilizing a spherical reaction torquer at the momentum level required for an interplanetary mission.

OPTIMIZATION OF INTERPLANETARY FLIGHT

On interplanetary flights as well as on lunar flights, it will be necessary to correct for the guidance and navigation errors to prevent excessive expenditure of fuel and to ensure that the vehicle reaches its proper destination. For example, very small angular deviations in the vehicle flight path initially can produce large distance errors in "hitting the target" when the range is thousands of miles. These initial angular deviations are dependent on the precision of both the guidance and navigation systems but, regardless of the precision involved, the flight path of any vehicle must be corrected because of the huge magnification effect of small initial errors over thousands or millions of miles. The optimization of the vehicle flight path is to correct for these flight path deviations (caused by guidance and navigation errors) with a minimum expenditure of fuel and time. Time enters as a factor in the optimization of flight path because:

1) If some correction is not made in a reasonable length of time, the effect of magnification of the initial error over long distances may get the vehicle so far off its flight path that getting back on course may be impossible.
2) The vehicle's destination is a moon or planet which is also moving and if the vehicle arrives at the designated point in space at some time later, then the moon or planet will be gone.

The optimization scheme chosen is somewhat dependent on the control mechanism used. For instance, if small solid-propellant rockets were used as the control mechanism, then the time between corrective thrusts must be longer and the total impulse correction would be greater since only a finite number of rockets could be used and their thrust could not be terminated and restarted. However, in using cold-gas jets or similar control mechanism, valves could be opened and closed at any time so that small impulse corrections could be made at frequent time intervals.

In a study by Potter[11] the guidance-navigation separation theorem applied to sampled data control systems by Gunkel and Joseph (in their Ph.D. theses) was extended to continuous time control systems. To obtain an optimum control system, it is generally essential to coordinate the design of the guidance and navigation systems such that the guidance system is as insensitive as possible to the anticipated navigation errors and the type of errors produced by the navigation system has a minimum effect on guidance. However, in the somewhat idealized example when the vehicle dynamical equations are linear and the cost function is

quadratic, the separation theorem states that the optimum control system is obtained when the guidance and navigation systems are designed separately without considering their interaction. In this study,[11] the Gunkel and Joseph separation theorem is proven for the continuous control case with navigation measurements contaminated with correlated noise. The dynamic programming approach utilized by Gunkel and Joseph is not used explicitly in this study although it is inherent in the method of proof. This analysis also applies to the sampled data case if the time integrals are replaced by sums, and provides a proof somewhat different than that of Gunkel and Joseph. The validity of the Gunkel and Joseph syntheses rests on the linearity of the vehicle dynamical equations, the navigation measurement process, and the use of a quadratic mission cost function. Experience has shown that linearizing vehicle dynamical equations leads to fairly accurate results and most navigation system design depends on linearizing the navigation measuring process. If the mission cost function is not quadratic, then it may still be reasonable to consider only the quadratic term in the Taylor series expansion of the cost function when carrying out a perturbation analysis about an optimum trajectory.

Dusek[12] performed an analysis of the effect of thrust-measuring instrumentation errors on astro-inertial guidance systems for low thrust interplanetary missions. In low thrust missions, precise thrust acceleration measurement in the range of 10^{-3} to 10^{-6} Earth-g's is required over a long flight time. In the study, it was assumed that acceleration forces were measured by accelerometers which were fixed with respect to an inertially stabilized platform and that measurements of a startracker (mounted on the same platform) were used to correct for the platform drift.

The conclusions[12] were that the position and velocity error in astro-inertial guidance systems for low thrust space missions can be intolerably large for accelerometer biases $(\alpha) = 10^{-5}$ g and moderate mission times. The critical parameter is the orientation of the force field vector generated by the bias error, with respect to the plane of the unperturbed motion. Small components of the perturbing field in this plane cause very large position and velocity deviations. The deviations will be negligible for all times only if the perturbing field is perpendicular to the plane of the unperturbed motion. This was shown rigorously for orbit-sustaining missions in the upper atmosphere using the method of separation of variables in Hamilton-Jacobi's partial differential equation. The developed linear perturbation theory was compared against the rigorous results. It shows sufficient validity over the time interval that is of interest for guidance purposes. The solutions also indicate several methods that promise an effective error

compensation such as rotation of the accelerometer with respect to the inertially stabilized platform, and/or employment of redundant position and/or velocity information.

CONCLUSIONS

The different design philosophies of Marshall Space Flight Center (i.e., inflight computation of an optimum trajectory using an onboard guidance computer of mostly logic circuits) and Massachusetts Institute of Technology (i.e., inflight comparison of flight path with a standard or a family of trajectories using an onboard guidance computer of mostly memory circuits) are complementary in the space effort. It is expected that many successful space guidance systems will evolve from both of these design philosophies. It is also anticipated that both system types will have their own inherent advantageous uses which will depend on the particular space mission to be accomplished and the various phases of each space mission.

The relative merits of using either Earth-based or onboard interplanetary navigation systems has received considerable attention in the past few years. It is realized that the Earth-based DSIF tracking network is very accurate to extensive distances and can utilize large, complex computers which would pose weight problems aboard the vehicle. However, it is also considered that, as the spacecraft journeys millions of miles into space, very minute angular errors in Earth-based measurements can become magnified distance errors out at the spacecraft regardless of the precision of the Earth tracking station. There are efforts to minimize these errors by using high measurement sampling rates and extensive computation and correlation of measurements to establish the most likely position for the vehicle. Many authors agree that some sort of terminal or approach navigation equipment will be necessary in the space vehicle for a planetary landing. The best solution seems to be to develop a vehicle-borne space navigation system that can be used in conjunction with National Aeronautics and Space Administration DSIF system such that the onboard system can operate independently, if necessary (in case of telemetry failure). Normally, the onboard navigation data could be correlated with DSIF navigation data to provide the best information under any and all circumstances.

The use of onboard startrackers seems to be preferable at the present time to the use of onboard horizon sensors in the determination of a space vehicle's position accurately because the star is a point source and angle of the horizon detected (by a horizon sensor) depends on variation in the characteristics of the atmosphere around a planet.

It has been said by some authors that inertial systems should be replaced by celestial navigation techniques because the errors in inertial equipment build up over the tremendous distances involved in interplanetary travel. However, other authors have stated that the use of inertial

systems periodically updated by the use of startrackers or other celestial navigation instruments seems to provide for the most efficient, continuous system.

LITERATURE CITED

1. Pickering, William H., Dr., SOME THOUGHTS ON GUIDANCE SYSTEMS, Astronautics and Aeronautics, Vol. 2, January 1964, pp. 70-73, A64-12083.

2. Fusca, James A., ADVANCED GUIDANCE CONCEPTS, Space/Aeronautics, Vol. 42, No. 7, December 1964, pp. 46-55.

3. Gates, C. R., Scull, J. R., and Watkins, K. S., SPACE GUIDANCE, ARS Paper 2113-61, October 1961.

4. Lally, Eugene, MOSAIC GUIDANCE FOR INTERPLANETARY TRAVEL, Astronautics, Vol. 7, No. 6, June 1962, pp. 60-64.

5. Alonso, Ramon L. and Hopkins, Albert L., THE APOLLO GUIDANCE COMPUTER, IEEE National Space Electronics Symposium - PTGSET Record - Paper 6.1, October 1963.

6. Hakes, Ralph C., GUIDANCE AND NAVIGATION SYSTEMS FOR LUNAR MISSIONS, ARS Reprint No. 2294-61, 15 October 1961.

7. Kochi, K. C. and Dibble, H. L., STELLAR TECHNIQUES FOR MIDCOURSE NAVIGATION-GUIDANCE, AIAA Paper 63-357, 12 August 1963, A63-21695.

8. Woestemeyer, F. B., APPROACH PHASE GUIDANCE FOR INTERPLANETARY MISSIONS, AIAA Paper 64-655, 26 August 1964, A64-23332.

9. Goldberg, Harold B. and Burrows, James L., A COHERENT SOLID-STATE RADAR FOR SPACE RENDEZVOUS AND PLANETARY LANDINGS, IEEE National Space Electronics Symposium - PTGSET Record - Paper 9.4, October 1963

10. Battin, Richard H., SPACECRAFT GUIDANCE AND NAVIGATION, Massachusetts Institute of Technology, Instrumentation Laboratory, In Winter Institute on Advanced Control, Third Space Vehicle Guidance and Control Proceedings, 19 February 1965, A65-19056.

11. Potter, James E., Dr., A GUIDANCE-NAVIGATION SEPARATION THEOREM, AIAA Paper 64-653, 26 August 1964, A64-23333.

12. Dusek, Hermann M., ERROR PROPAGATION IN ASTRO-INERTIAL GUIDANCE SYSTEMS FOR LOW-THRUST MISSIONS, AIAA Journal, Vol. 2, No. 5, May 1964, pp. 879-884, ARS Preprint 2682-62, A64-17793.

BIBLIOGRAPHY

Section I. INTERPLANETARY (OR LUNAR) FLIGHT

1. Guidance

1. Adams, C. R., et al.
TV, MODELS, AND MOSAICS USED TO GRADE SPACE-MANEUVERING ABILITIES, Society of Automotive Engineers Journal, Vol. 74, March 1966, pp. 78-79.

Not abstracted.

2. Aeronutronic, Newport Beach, California,
STUDY OF A MANNED MARS EXCURSION MODULE, VOLUME I OF III - PART I FINAL REPORT, 21 MAY - 20 NOVEMBER 1963 (U) by F. P. Dixon and T. W. Neumann. 20 December 1963, X64-14168 (Unclassified).

Not abstracted.

3. Air Force Systems Command, Wright-Patterson Air Force Base, Ohio,
AUTOMATIC STATIONS FLY TO THE PLANETS (U) by Y. Marinin, March 1963, TT 63 30, AD-402 442, N50121 (Unclassified).

Not Abstracted.

4. Air Force Systems Command, Wright-Patterson Air Force Base, Ohio,
GUIDANCE DEVELOPMENT AND NAVIGATION-EARTH SATELLITE CONTROL AND CONTROL SYSTEMS-DEFENSE AGAINST BALLISTIC MISSILES-STRUCTURES AND MATERIALS, VOLUME IV (U), Transactions of the Seventh Symposium on Ballistic Missile and Space Technology, 16 August 1962, AFSC Sym-BM&ST-7 (Secret).

Papers presented are in the following areas: guidance development and navigation, Earth satellite control and control systems, defense against ballistic missiles, and structures and materials.

5. Air Force Systems Command, Wright-Patterson Air Force Base, Ohio,
SPACE SYSTEMS GUIDANCE AND CONTROL, SPACE SYSTEMS LAUNCH VEHICLES, SPACE COMMUNICATIONS, VOLUME IV (U), Transactions of the Tenth Symposium on Space and Ballistic Missile Technology, 6 August 1965, AFSC Sym-BM&ST-10, AD-369 553 (Secret).

Not abstracted.

6. American Astronautical Society,
PRACTICAL CONSIDERATIONS FOR ASTRONAUTICAL GUIDANCE AND CONTROL by K. P. Gow and R. E. Roberson, 19 August 1958, AAS Preprint 58-30.

This paper discusses a number of the factors to consider when selecting a mechanization for guidance and attitude control of a space vehicle. The major environmental factors are summarized as they influence the mechanization, as are the implications of the propulsion method and the auxiliary power plant. The philosophy is proposed of selecting the mechanization primarily for reliability. This is in contrast to merely putting together a minimal collection of components that will perform the necessary navigation and guidance functions.

7. American Bosch Arma Corporation,
1962 GENERAL RESEARCH AND PRODUCE DEVELOPMENT PROGRAMS - SUMMARY TECHNICAL REPORTS (U), 31 December 1962, ARMA DR 62-E631-17 (Confidential).

The brochure summarizes the technical accomplishments of Arma's 1962 Independent Research and Development Program.

8. American Bosch Arma Corporation,
INERTIAL GUIDANCE FOR LUNAR PROBES, VOLUME III - FORMULATION AND EVALUATION OF THE GUIDANCE SYSTEM CONCEPT (U), November 1959, ARMA DR 220-17 (Confidential).

Not abstracted.

9. American Rocket Society,
ANALYSIS TECHNIQUES TO DETERMINE THE GUIDANCE COMPUTATION REQUIREMENTS FOR SPACE VEHICLES by G. Swanlund, 15 October 1961, ARS Reprint 2292-61.

This paper presents an approach to the determination of trajectories that is applicable to all phases of a space mission. The lunar mission has been considered as an example since it represents a typical complex mission. The topics covered are the mathematical models which are used to obtain the predicted motion of the trajectories, the synthesis techniques which are used to obtain the guidance laws which give the desired trajectories, and the techniques for determining the computation rate and accuracy requirements of the computer.

10. American Rocket Society,
A TERMINAL GUIDANCE SYSTEM FOR SOFT LUNAR LANDING by R. K. Cheng and I. Pfeffer, 9 August 1961, ARS Reprint 1912-61.

This paper was presented at the Guidance, Control, and Navigation Conference 7-9 August 1961, at Stanford University.

11. American Rocket Society,
THE APPLICATION OF RADIO INTERFEROMETRY TO THE GUIDANCE OF INTERPLANETARY ROCKETS by M. J. E. Golay, 1953, ARS Reprint 95-53.

The purpose of this report is to discuss the basic potentialities of radio-interferometry as applied to interplanetary rocket guidance.

12. Andeen, R. E. and Shipley, P. P.,
DIGITAL ADAPTIVE FLIGHT CONTROL SYSTEM FOR AEROSPACE VEHICLES, Vol. 1, pp. 1105-1109, May 1963.

Not abstracted.

13. Arguello, R. J. and Webber, A. L.,
CONTINGENCY ANALYSIS - SELECTION OF ALTERNATE OR BACK-UP GUIDANCE AND NAVIGATION MODES FOR MANNED SPACEFLIGHT, IEEE International Space Electronics Symposium, Record 6-9 October 1964, paper 5-a, 15 pp.

Techniques for selection of appropriate navigation and guidance modes from set of admissible modes for manned

spaceflight; underlying topological structure of mission flow chart is exploited in selection process; required topological concepts and illustrative example utilizing derived techniques are discussed.

14. Army Ballistic Missile Agency,
COMMENTS ON JPL PUBLICATION 30-3 "A STUDY OF SPACE GUIDANCE REQUIREMENTS" (U) by J. P. Calybourne and W. E. Rothe, 26 June 1959, ABMA DG-TR-11-59 (Secret).

JPL Publication 30-3 by C. R. Gates, dated 1 May 1959, concerns guidance and control of space vehicles. The objective of these comments is to propose a technique or method for integrating space guidance requirements and available guidance systems. The systems approach is employed, with maximum emphasis on reliability. A specific example is discussed to illustrate the approach.

15. Athans, M., Falb, P. L., and Lacoss, R. T.,
TIME-OPTIMAL VELOCITY CONTROL OF A SPINNING SPACE BODY, American Institute of Electrical Engineers, Winter General Meeting, New York, New York, 27 January through 1 February 1963, IEEE Transactions on Applications and Industry, July 1963, pp. 206-212; Discussion, pp. 213-214, A63-21781.

Examination of the problem of minimum-time angular velocity control of a spinning space body, with a single axis of symmetry. The control thrusts are assumed bounded. Two-axis, gimballed, and single-axis controls are considered. The optimal controls law is derived for each method. Comparison of the response times indicates that gimballed control is best.

16. Author Unknown,
AEROSPACE IN PERSPECTIVE; CONTROL, Space/Aeronautics, Vol. 41, January 1964, pp. 138-155.

Not abstracted.

17. Author Unknown,
AMERICAN ROCKET SOCIETY GUIDANCE, CONTROL, AND NAVIGATION CONFERENCE, STANFORD UNIVERSITY, 7-9 AUGUST 1961, Space/Aeronautics, Vol. 36, November 1961, pp. 143-150.

Not abstracted.

18. Author Unknown,
APOLLO GUIDANCE AND NAVIGATION NEARS PRODUCTION, Control Engineering, Vol. 10, November 1963, pp. 23-24.

Not abstracted.

19. Author Unknown,
ARTIFICIAL SATELLITES AND THE PROBLEMS OF INTER-PLANETARY FLIGHTS (Foreign title not available), Translated into English from Russian by Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, N63-18436 (Soviet Satellites and Space Ships, Selected Articles, 23 February 1962, pp. 64-72, N63-18430 17-32).

The steps for accomplishing the interplanetary flights with the use of artificial satellites are explored. The basic stages by which mankind will accomplish flights to other celestial bodies include: (1) preparatory research of the basic problems of spaceflight with automatic artificial satellites of the Earth, (2) the creation of artificial satellites of the Earth with people on them and permanent artificial-satellite stations, (3) the accomplishment by man of flights to the moon and nearby planets without landing on their surfaces, and (4) study of the different planets of the solar system by the organization of expeditions to them.

20. Author Unknown,
ASTRODYNAMICS, GUIDANCE, AND CONTROL CONFERENCE, 24-26 AUGUST 1964, Astronautics and Aeronautics, Vol. 3, January 1965, pp. 66-68.

Not abstracted.

21. Author Unknown,
GUIDANCE AND CONTROL FOR MANNED LUNAR FLIGHT; SPECIAL REPORT, Control Engineering, Vol. 9, June 1962, pp. 87-102.

Not abstracted.

22. Author Unknown,
GUIDED FLIGHT SIMULATION AND ANALYSIS: ABSTRACTS OF PAPERS PRESENTED AT EASTERN SIMULATION COUNCIL MEETING, 15 APRIL 1963, Instruments and Control Systems, Vol. 36, July 1963, p. 143.

Not abstracted.

23. Author Unknown,
MARINER MIDCOURSE MANEUVER, Control Engineering, Vol. 12, January 1965, p. 26.

Not abstracted.

24. Author Unknown,
PECULARITIES OF MOTION OF SPACE VEHICLES IN THE SOLAR SYSTEM. FLIGHTS TO THE MOON, MARS, AND VENUS. MAN-MADE PLANETS (Foreign title not available), Translated into English from Russian by Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, N63-18432 (Soviet Satellites and Space Ships, Selected Articles, 23 February 1962, pp. 18-36, N63-18430 17-32).

The motion of space vehicles in the solar system flights to the moon, Mars, and Venus is studied. The aspects of motion investigated include: the dependence of the angle of inclination of the velocity vector upon the range angle, duration of flight of spacecraft to the moon, the dependence of the velocity of a space vehicle at the boundary of Earth's sphere of influence upon its velocity at the end of the ejection phase, distance from the sun to the perihelion of the orbit at various velocities at the end of the ejection phase, values of the minimum velocities for flights to the planets, orbits of flights to Mars, values of total velocity necessary for ejection of space vehicle into circular orbit about the sun, and orbits of flights to Venus.

25. Author Unknown,
PROJECT RANGER, Spaceflight, Vol. 4, No. 2, March 1962, pp. 47-51.

This article presents: scope of project, managed by Jet Propulsion Laboratory; description of launch vehicle Atlas Agena B and of spacecraft Ranger; and spacecraft controller and sequence of 10 commands issued to Ranger by spacecraft controller.

26. Author Unknown,
SECOND MANNED SPACE FLIGHT MEETING. 22-24 APRIL 1963, New York, American Institute of Aeronautics and Astronautics, 1963, 397 pp., A63-18980.

Collection of papers treating various aspects of the U. S. space program is presented, with emphasis on manned space flight. Specific topics covered include the design, structure, and fuel problems in Projects Mercury, Gemini, and Apollo. Also discussed are methods of simulation, environmental effects, aeromedical and astrobiological investigations, radiation shielding, management problems, guidance and navigation systems, life-support systems, reentry physics, and electric and nuclear propulsion systems. The papers are individually abstracted and indexed in this issue.

27. Author Unknown,
SPACE VEHICLES; TWO MAJOR CHALLENGES FROM SPACE TO THE CONTROL ENGINEER, Control Engineering, Vol. 12, January 1965, pp. 82-83.

Not abstracted.

28. Author Unknown,
STEREO COLOR TV SYSTEM MAY GUIDE MOON ROBOT, Electronics, Vol. 34, 13 October 1961, pp. 30-32.

Not abstracted.

29. Autonetics, Anaheim, California,
EXTENDED APOLLO SYSTEMS UTILIZATION STUDY, VOLUME 15 - ALTERNATE GUIDANCE SYSTEM (U) by J. N. Schmidt, 16 November 1964, X65-12275 (Confidential).

Not abstracted.

30. Autonetics,
A "UNIVERSAL" LINEAR GUIDANCE MECHANIZATION FOR SPACE SYSTEMS by K. C. Kochi, 25 June 1963, TM 243-2-153 (Unclassified).

This report details a linear, fixed-time-of-arrival, guidance mechanization theory for space systems in the free-fall regime. Emphasis is placed on development of basic sets of explicit guidance mechanization equations having "universal" applications.

31. Avco Corporation, Wilmington, Massachusetts,
LOW-THRUST VEHICLE GUIDANCE STUDY: VOLUME II, PARTS II AND III by J. S. Miller, J. M. Dahlen, and R. J. Magee, August 1961, R-333, AD-606 019, N50121 (Unclassified).

This report considers various aspects of the guidance of a low-thrust vehicle. The report is divided into three parts: theory, guidance system implementation, and space sextant feasibility demonstration. The first part on theory presents a guidance scheme suitable for use on an arc-jet vehicle in an Earth to lunar orbiting mission. Numerical results are presented which demonstrate the capability and performance of this scheme. The second part presents implementation schemes for a self-contained guidance and attitude control system for a lunar reconnaissance mission. The system uses a precise automatic space sextant supported by two mechanical degrees-of-freedom as a primary source of guidance and attitude control information. The third part reports on a laboratory experimental program to demonstrate the feasibility of the space sextant. Included are a physical description of the instrument and complete error analysis.

32. Barabush, A.,
SOFT LUNAR LANDING GUIDANCE SENS(, American Astronautical Society, Lunar Flight Sympc um, New York, New York, 27 December 1960, Lunar Exploration and Spacecraft Systems, New York, Plenum Press, 1962, pp. 153-167, A63-1?472.

Description of the initial design characteristics of a soft-lunar-landing guidance sensor capable of controlling the astronautical retrorocket-type devices to be used to effect the lunar landing. It is indicated that the sensor must account for the vehicle altitude, its vertical velocity (vector), and its lateral

velocity (vector). With these parameters known, the landing can be controlled until final touchdown is accomplished. Lunar-landing radar parameters are tabulated, and a block diagram for the landing sensor is included.

33. Barker, L. K. and Sparrow, G. W.,
ANALYSIS OF A SIMPLE TECHNIQUE FOR ESTABLISHING LUNAR ORBITS, American Institute of Aeronautics and Astronautics, Annual Meeting, 2nd, San Francisco, California, 26-29 July 1965, Paper 65-436, A65-29710.

Analytical study of a simplified guidance technique designed to place a spacecraft that departs from Earth in a close orbit around the moon. The technique consists of maintaining a constant angle between the thrust axis of the spacecraft and the line of sight to the lunar horizon while the orbit is being established. The nominal approach trajectory which was used had a transit time of 70.5 hr, a minimum altitude of 80 n mi, and a velocity at this point of 8308 fps. It was found that parking orbits which are closely confined to the pericynthion altitude of the approach trajectory (80 n mi) can be established very efficiently by use of the simplified guidance technique.

34. Battin, R. H.,
ASTRONAUTICAL GUIDANCE, New York, McGraw-Hill Book Company, 1964, 400 pp., A64-22801.

This book provides a background for understanding the problems of astronautical guidance, stressing the requirements of a self-contained system. Topics include: (1) an introduction to celestial mechanics covering the law of universal gravitation, potential of distributed mass, the n-body problem, the disturbed motion of two bodies, the sphere of influence, the two-body problem, orbital elements and coordinate systems, and orbit determination; (2) position and velocity in two-body orbits including conic sections, semimajor axis and energy integral, position and velocity in parabolic orbits, orbital anomalies and Kepler's equation, methods of solving Kepler's equation, position and velocity in elliptic and hyperbolic orbits, universal formulas for conic orbits; (3) two-body orbit determination covering geometrical relations, Lambert's theorem for time of flight, and spacecraft-trajectory determination; (4) two-body orbital transfer including the envelope of accessibility, single- and

two-impulse orbital transfer, hodograph analysis, injection velocity, and powered-flight guidance; (5) trajectories and missions for space flight and procedures for calculating the conic arcs; (6) perturbation methods including the osculating orbit, the variational method, perturbation matrices, and the explicit calculation of the perturbation matrices; (7) celestial navigation covering the geometrical description of the navigation fix, measurements, mathematical analysis of the navigation fix clock errors, maximum-likelihood estimation, and error analysis; (8) interplanetary guidance and navigation using celestial fixes including guidance theory and multiple-fix navigation; (9) recursive navigation theory covering the state-transition matrix, recursive formulation of the navigation problem, statistical analysis of the guidance procedure, and optimization procedures; and (10) guidance theory for a continuous low-thrust lunar reconnaissance vehicle. Problems are presented at the end of each chapter, and there is an appendix covering constants and physical data. The book is intended for the use of research scientists as well as students.

35. Bellman, R., Dreyfus, S., and Kalaba, R.,
APPLICATIONS OF DYNAMIC PROGRAMMING TO SPACE GUIDANCE, SATELLITES, AND TRAJECTORIES, Planet Space Science (GB), Vol. 7, July 1961, pp. 176-178.

Included is a short note on a new computational technique based on the theory of dynamic programming and applicable to trajectory problems. As an example, the classical problem of the brachistochrone is considered by the new method and it is shown that the answer is the same as that obtained by the calculus of variations.

36. Blasingame, B. P.,
GUIDANCE AND NAVIGATION PROBLEM AREAS FOR INTERPLANETARY MISSIONS, International Astronomical Union-Douglas Aircraft Company, Inc., International Symposium on Space Age Astronomy, Pasadena, California, 7-9 August 1961, Space Age Astronomy, New York, Academic Press, Inc., 1962, pp. 510-514, A63-14384.

Included is a study of the requirements for midcourse vehicular control and presentation of design parameters that will ensure accuracy and reliability and enhance payload capability. For interplanetary missions, it is believed that an optical-inertial system combined with a central computer will be necessary. The reliability problem is considered the greatest obstacle to the attainment of a successful system.

37. Blasingame, B. P. and Christensen, R. R.,
SPACE GUIDANCE AND CONTROL, Space Logistics Engineering, New York, John Wiley and Sons, Inc., 1962, pp. 162-198, A63-13954.

Included is a discussion of a manned lunar landing and the problems of guidance and control of the lunar vehicle from its launch to its return to Earth. A statement of Kepler's laws of planetary motion and Newton's law of universal gravitation provide the framework for the development of ICBM free-fall orbits. The error sensitivity of these orbits leads to the mechanization of a guidance system. These considerations are then applied to a predetermined controllable lunar orbit that can account for launch errors and uncertainties in astronomical constants. The boost, midcourse, and terminal phases of a lunar mission are outlined and the factors involved in a return trajectory are discussed. A distinction is then made between the automated and manual functions performed in a manned lunar mission.

38. Boeing Company, Seattle, Washington,
PROPULSIVE TRANSFER BETWEEN HYPERBOLIC ASYMPTOTES AND ITS APPLICATIONS IN INTERPLANETARY MISSION PLANNING by D. S. McKellar, July 1964, D2 23398, AD-445 085L, N50121 (Unclassified).

The use of propulsion during planetary encounter can ease considerably the timing restrictions normally associated with interplanetary flyby missions. A velocity impulse applied near the sphere of influence provides a speed change, as well as any turn not supplied by the planet. With any combination of outbound and return legs thus made available, the only restrictions on launch, encounter, and return dates are due to launch weight considerations. Viewing Mars flyby missions in 1971 from this standpoint gives rise to four observations: (1) no propulsive flyby offers a launch weight less than that required for the best free-return; (2) when launch and return dates are fixed, the encounter date giving the lowest velocity increment at Mars does not necessarily give the lowest launch weight; (3) for darkside passages, there is a 20-day launch span in which propulsive flybys offer launch weights less than 10 percent greater than that required for the lowest-weight trip in the 1971 era; (4) most of the benefits of propulsive flybys occur for velocity increments less than 2000 fps.

39. Boeing Company, Seattle, Washington,
VOYAGER SYSTEM REQUIREMENTS by J. W. Highberg, November 1963, D2 22893, AD-443 146L, N50121 (Unclassified).

The purpose of the Voyager project is the scientific exploration of Mars and Venus using spacecraft designed for use with Saturn boost vehicles. The primary objective is the scientific exploration of Mars and Venus and of the interplanetary space in the Mars-Venus region. A secondary objective is the determination of the feasibility of manned flights of these planets. These early missions will develop the technology and collect the scientific data required for future more advanced projects.

40. Bold, N. T. and Dibble, H. L.,
GUIDANCE AND NAVIGATION FOR LOW-THRUST SPACE VEHICLES, Institute of Navigation, Space Navigation Meeting, St. Petersburg, Florida, 30 April through 1 May 1964, Paper, 22 pp., A64-25789.

Included is a discussion of system requirements for space missions in which electric thrustors are used. Useful payloads, times of flight, and efficiencies of some low-thrust space missions are reviewed. It is noted that electric thrustors provide significant advantages over the exclusive use of chemical propellants, i.e., useful payloads can be increased while time of flight is decreased. The navigation-guidance problem for low-thrust space missions is examined, and it is said to appear that the system requirements are substantially more demanding than that in all previous development work. Not only must the system be capable of measuring very small thrust-vectors, but it must also operate with high reliability for extended periods of time without requiring an excessive amount of power. Additional requirements of the system are said to be for light weight and low volume. It is believed that present-day guidance systems may not fulfill the requirements of low-thrust space missions; it is said to appear that a new system may be required. Such a system, it is thought, should be the result of analytical studies which consider optimum guidance mechanizations, specific trajectory profiles, system specifications, detailed error analyses, detailed reliability requirements, and system trade-off parameters. Furthermore, it is believed that for low-thrust missions, the present techniques for determining position, velocity, and time of arrival are inadequate and require revision.

41. Breakwell, J. V., et al,
APPLICATION OF THE CONTINUOUS AND DISCRETE STRATEGIES OF MINIMUM EFFORT THEORY TO INTERPLANETARY GUIDANCE, AIAA Journal, Vol. 3, May 1965, pp. 907-912.

Not abstracted.

42. Breakwell, J. V., Tung, F., and Smith, R. R.,
APPLICATION OF THE CONTINUOUS AND DISCRETE STRATEGIES OF THE MINIMUM EFFORT THEORY TO INTERPLANETARY GUIDANCE, American Institute of Aeronautics and Astronautics, and Institute of Navigation, Astrodynamics Guidance and Control Conference, Los Angeles, California, 24-26 August 1964, Paper 64-664, 12 pp., A64-23833, Contract No. NAS1-3777.

Not abstracted.

43. Breakwell, J. V., Helgostam, L. F., and Krop, M. A.,
GUIDANCE PHENOMENA FOR A MARS MISSION, Proceedings of the American Astronautical Society Symposium on the Exploration of Mars, Denver, Colorado, 6-7 June 1963, (Advances in the Astronautical Sciences, Vol. 15), Exploration of Mars, North Hollywood, California, Western Periodicals Co., 1963, pp. 252-273, A64-10111.

The principal guidance phenomena for a manned nonstop round-trip to Mars are sought by geometric, mathematical, and physical examinations of the trajectory and its sensitivity to small perturbations. The two major findings are: (1) the deviations from the nominal trajectory in both the early and the final stages of the midcourse portions of each leg of the trip are fairly well described by uncoupled, straight-line motion, and (2) with reasonably good optical sighting accuracy, such as a standard deviation of 10 sec of arc in optical sightings on the planets against the star background, the entire interplanetary midcourse navigation and guidance problem can be solved in the vicinity of the two terminal planets with a modest expenditure of corrective velocity. On most relatively short-duration interplanetary trips it is advantageous to employ variable-time-of-arrival guidance procedures. On the relatively long trips, it is advisable to guide for fixed time of arrival early in the trip and variable, later. Guidance in the final phase of the midcourse appears to be amenable to fairly simple, straightforward methods based on observing only the magnitude and the direction of the angular rate of change of the line of sight to the target planet.

44. Brickel, J. R., Hackler, C. T., Smith, H. E., and Cheatham, D. C.,
LEM PILOTED CONTROL CONSIDERATIONS, American Institute of Aeronautics and Astronautics, and Institute of Navigation, Guidance, and Control Conference, Minneapolis, Minnesota, 16-18 August 1965, Paper, 90 pp., A66-15166.

Included is a discussion regarding the lunar excursion module (LEM) mission and the pilot's role in spacecraft control, including a brief description of the LEM guidance and control systems, the methods of guidance in various mission phases, and the G and C pilot interfaces. The Apollo LEM, it is noted, must provide the crew with the means for retromaneuvering out of lunar orbit, decelerating to a soft landing, and then, after a time on the lunar surface, accelerating back into orbit for rendezvous. The primary areas of pilot control in the various phases are examined in detail. Guidance monitoring, landing-site inspection, manual updating of the guidance system, landing, and terminal rendezvous are described. Pilot interface with the primary navigation and guidance control system is through display and keyboard, rotational hand controllers, descent engine throttles, and an optical telescope.

45. Buscher, R. G.,
SELF-ADAPTIVE VERSUS CONVENTIONAL FLIGHT CONTROL, Control Engineering, Vol. 10, January 1963, pp. 102-103.

Not abstracted.

46. Burgess, E.,
ADVANCES IN THE ASTRONAUTICAL SCIENCES, VOLUME 13, American Astronautical Society, Annual Meeting, 9th, Los Angeles, California, 15-17 January 1963, North Hollywood, California, Western Periodicals Co., 1963, 682 pp., A63-23385.

Included is a collection of papers dealing with various aspects of interplanetary missions. Considered are launch and boost systems for such missions, interplanetary flight, planetary entries, bases and exploration, and different areas of advanced research, including studies of meteoroid penetration. The papers are individually indexed and abstracted in this issue.

47. Busby, L. A.,
HIGH ALPHABET COMMAND DECODER FOR SPACEBORNE VEHICLES, Space Electronics Symposium; Proceedings of the Joint American Astronautical Society and Aerospace Electrical Society Meeting, Los Angeles, California, 25-27 May 1965, New York, American Astronautical Society, 1965, pp. IV-23 to IV-36, A65-34480, A65-34466.

Included is an application of advanced techniques to the problem of command and control of space vehicles. The message encoding technique involves both the frequency and time domains, so that improved performance is obtained over simple systems which encode only in either domain, particularly in weak signal or interference environments. Improved reliability of signal processing is obtained not only by the reduction of internal components resulting from use of a high alphabet (multitone) technique but also by the use of simple yet high effective internal redundancy. Reliability is further enhanced by circuitry which removes voltage stress in the standby mode. In order for a command system to realize the full benefit of the extremely high MTBF of this unit, the decoder is driven from two redundantly connected receivers. Parallel inputs are provided for this purpose. A short circuit at either receiver output does not cause system failure. The high alphabet approach yields a very low ratio of active components to total command functions. The system provides 216 distinct commands (or 108 fully redundant commands) for a total investment of only 1.9 active components per command. The decoder is compatible with signal formats presently used by NASA ground stations.

48. Carley, R. R. and Cheatham, D. C.,
GEMINI GUIDANCE AND CONTROL, International Astronautical Federation, International Astronautical Congress, 16th, Athens, Greece, 13-18 September 1965, Paper, 44 pp., A66-15924.

Included is a review of the mission objectives and brief description of the Gemini guidance and control system. The Gemini mission objectives are: (1) long-duration missions, (2) the development of an operational rendezvous capability, (3) the development and evaluation of a controlled reentry capability, and (4) the development of flexible systems. Design considerations discussed include redundancy and reliability, ground monitoring, abort considerations, and guidance and control system implementation. The control and guidance

system is shown. The Gemini flights completed have demonstrated the launch guidance capacity, one of the two reentry guidance techniques, orbit maneuvering, and orbit and reentry attitude stabilization and control.

49. Cashmore, D. J.,
ROLE OF INERTIAL EQUIPMENT, British Interplanetary Society Journal, Vol. 18, No. 4, July-August 1961, pp. 138-148.

Included is a survey of navigation and guidance problems associated with flight between Earth and moon; how magnitude of nominal initial velocity strongly affects requirements for various missions; aspects of problem not solved by present day guidance of ballistic missiles are midcourse navigation, reliability and safety, and flexibility; and use of inertial equipment is proposed during boost phases of lunar vehicle and for monitoring midcourse correction maneuvers, as part of single integrated system of navigation and guidance.

50. Chamberlin, J. A.,
GUIDANCE SYSTEMS, Manned Spacecraft - Engineering Design and Operation, New York, Fairchild Publications, Inc., 1964, pp. 203-211, A65-12550.

Included is a discussion of the guidance and control requirements and systems for the Mercury, Gemini, and Apollo manned spacecraft and of their applicability to other missions. Mission requirements are reviewed, as is the basic design philosophy. Guidance sensors described are time references, inertial sensors, and optical systems to provide position references, including horizon scanners, sextants, and radars. Computers for data processing and calculations, and data displays, are also covered.

51. Chapman, R. C., et al,
COMMAND AND TELEMETRY SYSTEMS, Bell System Technical Journal, Vol. 42, July 1963, pp. 1027-1062.

Not abstracted.

52. Cherry, G. W.,
A UNIFIED EXPLICIT TECHNIQUE FOR PERFORMING ORBITAL INSERTION, SOFT LANDING, AND RENDEZVOUS WITH A THROTTLEABLE ROCKET-PROPELLED SPACE VEHICLE, American Institute of Aeronautics and Astronautics, Guidance and Control Conference, Cambridge, Massachusetts, 12-14 August 1963, Paper 63-335, 23 pp., A63-21692.

Included is a presentation of a family of guidance laws for the provision of rocket steering and throttling commands during the principal engine-on phases of a planetary reconnaissance and landing. The guidance laws are derived as explicit solutions to the two-point boundary-value problems of guided powered trajectories. An explicitly formulated ICBM guidance law permits the rapid change of missile direction. Analogously, an explicitly formulated lunar-landing guidance law allows the rapid respecification of the landing point or the immediate substitution of an ascent abort trajectory for the landing trajectory, all under control of the same computer program. An illustrative mission is chosen to demonstrate the explicit guidance method. The phases discussed are orbital insertion from the hyperbolic approach trajectory, soft landing of an exploratory module at a specified site, and ascent of the exploratory module from the planetary surface to a point where the terminal rendezvous phase can be initiated. For the mechanization of the guidance schemes a vehicle-borne digital computer and navigation system is assumed. The navigation subsystem determines for the computer the instantaneous position and velocity of the spacecraft, the first "point" of the two-point boundary value problem. The second "point" is the terminal or burnout point at which some or all of the coordinates of position and components of velocity are specified. These terminal conditions can be determined before launch and stored in the computer, computed in flight by subroutines in the computer, or placed into the computer by an astronaut.

53. Cherry, G. W.,
CLASS OF UNIFIED EXPLICIT METHODS FOR STEERING THROTTLEABLE AND FIXED-THRUST ROCKETS, Astronautics and Aeronautics, Vol. 13, pp. 689-726, 1964.

Included is a generation of class of explicit guidance laws for computing rocket steering and throttling commands; commanded thrust vector can be computed in-flight as explicit solution to two-point boundary-value problem; commanded thrust vector is found by direct solution of equations of motion subject

to initial boundary condition of vehicle's instantaneous measured state and final boundary condition of vehicle's desired state; and three principal thrusting phases of lunar reconnaissance and landing mission are given.

54. Cherry, G. W., DESIGN PRINCIPLES FOR AN INTEGRATED GUIDANCE AND CONTROL SYSTEM FOR THE LUNAR EXCURSION MODULE, American Institute of Aeronautics and Astronautics, Manned Space Flight Meeting, 4th, St. Louis, Missouri, 11-13 October 1965, Technical Papers, A66-11613 02-05, New York, American Institute of Aeronautics and Astronautics, 1965, pp. 145-157, A66-11628.

Included are design principles of a primary guidance and control system for the lunar excursion module, consisting of a powerful digital guidance computer, an inertial measurement unit (IMU), and other navigational sensors, which also performs the functions of a spacecraft autopilot and a stabilization and control system. The integrated guidance and control system can be analyzed into a slow, outer (path control) loop, and a fast, inner (thrust vector control) loop. The outputs from the accelerometers in the IMU are integrated to obtain navigation feedback for the path control loop. The IMU gimbal angle measurements are processed in an optimum linear recursive filter to provide feedback for the inner loop. The outer loop computes a solution thrust acceleration vector program explicitly in terms of the current vehicle state and desired vehicle state. The inner loop issues reaction control system jet on-off commands and trim-gimbal drive signals to attain an economical limit cycle about the altitude and attitude rate commanded by the path control loop.

55. Citron, S. J., Dunin, S. E., and Meissinger, H. F., A SELF-CONTAINED TERMINAL GUIDANCE TECHNIQUE FOR LUNAR LANDING, APPENDIX - PROPERTIES OF THE OFFSET GRAVITY TURN DESCENT, American Rocket Society, Annual Meeting, 17th, and Space Flight Exposition, Los Angeles, California, 13-18 November 1962, Paper 2685-62, A63-12344.

Included is a presentation of a method for soft landing at predetermined points on the lunar surface, using a self-contained guidance system which may be applied to either hyperbolic approach or descent from a parking orbit. During

descent a computer carried by the vehicle compares the predicted and desired landing-point coordinates. Two feedback loops are operative - soft-landing control and pin-point landing guidance. The soft-landing control constrains the thrust level so as to terminate the trajectory at the lunar surface with zero velocity. The pin-point guidance drives the downrange and crossrange components of the landing-point error to zero. Separation of the two control functions has the advantage of assuring a safe landing in the event of component failures in the pin-point guidance subsystem. Simulation studies have shown that this technique is quite effective. Analytical closed-form solutions are obtained to determine, at any time during descent, the thrust acceleration level required and the predicted landing point. For trajectories following a shallow descent, as from a parking orbit, the circular geometry of the moon is treated. For trajectories which initially make large angles with the local horizon, or have small velocities, the moon is considered flat. Verification of the analysis was obtained by comparison of the results with computer solutions of the exact equations.

56. Citron, S. J., Dunin, S. E., and Meissinger, H. F., A TERMINAL GUIDANCE TECHNIQUE FOR LUNAR LANDING, American Rocket Society, Annual Meeting, 17th, and Space Flight Exposition, Los Angeles, California, 13-18 November 1962, AIAA Journal, Vol. 2, March 1964, pp. 503-509, A64-15147.

Not abstracted.

57. No entry.

58. Collins, D. L., SPACE VEHICLE CONTROL BY PRECISION DISCRETE TIME FUNCTIONS, IRE 5th National Symposium on Space Electronics and Telemetry - Trans 1960, 7 pp.

One method of integrating signals from missile Earth reference and missile computer is through precision discrete time function programmer; basic design principles of discrete time function programmer are discussed and two such programmers described.

59. Da-Riva, I., Fraga, E., and Linan, A.,
INTERPLANETARY PROBES (Sondas Interplanetarias), Ingeniería Aeronáutica y Astronáutica, Vol. 17, 17 March - April 1965, pp. 1-27, A65-28581.

Included is a study of launching parameters of probes which can escape the Earth's sphere of influence and move mainly under the sun's attraction. A series of simple relations are obtained which make it possible to reasonably approximate the launching conditions necessary to accomplish a specific space mission. The theory is applicable to a wide range of missions, in particular those of comet interception which require unique approximate methods. The method of matched conics is used to study the trajectory of the probe. A linearized theory of interplanetary flight is presented which simplifies the determination of the launching parameters to reach a specific goal. As an example, an analysis of the Pioneer V space flight is included.

60. Darlington, S.,
GUIDANCE AND CONTROL OF UNMANNED SOFT LANDINGS ON THE MOON, Planetary and Space Science (GB), Vol. 7, July 1961, pp. 70-75.

A guidance and control scheme is described, which may be appropriate for early unmanned soft landings on the moon. The principal components are: a precision launch phase guidance system; a preset direction and attitude control; main and vernier retrorockets of the solid fuel, fixed impulse type; a range only, pencil beam radar, nonsteerable relative to the air frame; and means for firing the retrorockets at preset radar ranges to the moon's surface. No means are included for measuring the errors in the burning of the main retrorocket, and yet the vernier is so used that the effects of the errors are largely suppressed.

61. Defense Documentation Center, Alexandria, Virginia,
SPACE RENDEZVOUS, RESCUE, AND RECOVERY, A DDC ABSTRACT COMPILATION by P. C. Rogers, August 1963, AD-410 085 (Unclassified).

This bibliography was prepared for the specialist meeting on space rendezvous, rescue, and recovery held at Edwards Air Force Base on 10-12 September 1963. Citations are included for reports data logged by DDC from 1953 to June 1963 and are restricted to unclassified, unlimited references.

References are arranged by the following subject headings: rendezvous guidance, control and/or propulsion; docking systems; crew transfer techniques; space rescue operations; assembly techniques for orbital operations; effects of launch time delays; recovery from space; reentry forces and heating; control center operations; simulation techniques; instrumentation and displays; spaceborne computers and data processing; radar, optical, IR, UV, magnetic, and nuclear sensors; space tracking, cummunications and telemetry; life support requirements; environmental control systems; medical considerations for space and rescue missions; astronaut training requirements; and characteristics of USSR Vostoks.

62. Denham, W. F. and Speyer, J. L., OPTIMAL MEASUREMENT AND VELOCITY CORRECTION PROGRAMS FOR MIDCOURSE GUIDANCE, AIAA Journal, Vol. 2, No. 5, May 1964, pp. 896-907.

Included is an estimation and control of perturbations in preplanned midcourse portion of space mission trajectory; optimization of measurement program, state estimator, and/or feedback control gain program is investigated; performance index is scalar function of expected values of quadratic forms in perturbations and/or in errors in estimates of perturbations; conditions for desired extremal solutions and steepest-ascent computation procedure for obtaining approximate optimizations are presented; numerical example relating to minimum terminal uncertainty in translunar navigation through optimal measurement sequencing.

63. Denton, C. I., et al, SPACE RENDEZVOUS GUIDANCE AND DOCKING TECHNIQUES, Westinghouse Engineer, Vol. 22, July 1962, pp. 98-102.

Not abstracted.

64. Directorate of Scientific Intelligence, Canada, RADIO CONTROLLED ROCKETS by I. Kucherov, translated by E. E. Budzinski, January 1956, 6 pp. (Translation No. 13 from Radio 8:50-53, 1955), Report No. IR 420-56, AD-106 993 (Unclassified).

Not abstracted.

65. Doennebrink, F. A. and Rifkin, A. R.,
FLIGHT CONTROL, Space/Aeronautics, Vol. 44, No. 2, 1965-1966, pp. 80-84.

Not abstracted.

66. Donovan, R. F.,
DEVELOPMENT OF A FLIGHT CONTROLLER FOR THE DELTA SPACE RESEARCH VEHICLE, Applications and Industry, November 1960, pp. 406-411.

Not abstracted.

67. Douglas Aircraft Company, Inc.,
PRESENTATION ON THE DIANA-A SPACE PROBE VEHICLE (U), January 1960, Douglas SM-36318 (Confidential).

This report shows the capabilities of a two stage general purpose space vehicle using a modified Thor booster and a high-energy propellant second stage with restart capability. The vehicle capabilities for Earth satellites and interplanetary probes are also evaluated and are displayed in this document.

68. Dusek, H. M.,
APPLICABILITY OF LINEAR PERTURBATION THEORY IN MIDCOURSE GUIDANCE, ARS Journal, Vol. 32, August 1962, pp. 1287-1289.

Not abstracted.

69. Dusek, H. M.,
THEORY OF ERROR COMPENSATION IN ASTRO-INERTIAL-GUIDANCE SYSTEMS FOR LOW-THRUST SPACE MISSIONS, Astronautics and Aeronautics, Vol. 13, 1964, pp. 755-774.

Techniques proposed to compensate guidance errors in aided-inertial guidance systems for long-term, low-thrust space missions are rotation of accelerometers with respect to inertially stabilized platform, statistical filtering of redundant position and/or velocity information and output of inertially fixed accelerometers, and combination of statistical filtering and rotation of accelerometer; effectiveness of techniques is analyzed; and analytical and numerical results are given.

70. Electronic Associates, Inc., Research and Computation Division, Princeton, New Jersey,
HYBRID COMPUTATION FOR SIMULATION OF THE MOTION OF AEROSPACE VEHICLES by E. E. L. Mitchell, W. G. Hagerbaumer, and J. B. Mawson, July 1964, AD-464 829, N50121 (Unclassified).

After a basic introduction to the equations of motion of a rigid body and a discussion of coordinate systems appropriate to aerospace flight, general purpose programs are developed for use in the hybrid simulation of the motion of an aerospace vehicle for various flight regimes. Detailed programs are included for the digital section covering full mission. Footprint display and digital function generation are also discussed.

71. Fargel, L. C. and Ulbrich, E. A.,
PREDICTOR DISPLAYS EXTEND MANUAL OPERATION, Control Engineering, Vol. 10, August 1963, pp. 57-60.

Not abstracted.

72. Faulkner, A. H., Gurzi, F., and Hughes, E. L.,
MAGIC - AN ADVANCED COMPUTER FOR SPACEBORNE GUIDANCE SYSTEMS, Institute of Radio Engineers, Conference on Spaceborne Computer Engineering, Anaheim, California, 30-31 October 1962, Paper, 22 pp., A63-15464.

Included is a description of a special-purpose digital computer designed specifically to provide the computational capability required in an advanced stellar-inertial guidance system for a rocket-launched space vehicle. It is a programmable, whole-number, binary digital computer with an adequate but not elaborate instruction repertoire. It uses a serial coincident-current, torroidal-core memory with a capacity of 4096 words of 24-bits each. The logic parts of the computer are implemented with Fairchild Micrologic elements, and those parts which could not be implemented with integrated circuits are constructed of conventional components in welded and encapsulated modules.

73. Fernandez, M.,
SOLUTION OF FREE-FALL GUIDANCE AND CONTROL PROBLEM IN N-BODY SPACE, IEEE Transactions on Military Electronics, Vol. MIL-7, No. 1, January 1963, pp. 9-14.

Solution of free-fall guidance and control problem in inverse-square central force field is treated; this is then extended to solution of free-fall guidance problem in N-body space; in latter category, Bonnet's Theorem, as extended by Egorov, is covered to show its application to solution of N-body problem; equations discussed are valid for vehicle of negligible mass acted upon by forces due only to N inverse-square central force fields.

74. Forney, R. G., et al,
MARINER 4 MANEUVER AND ATTITUDE CONTROL, Astronautics and Aeronautics, Vol. 3, October 1965, pp. 36-39.

Not abstracted.

75. Foster, J. V.,
GUIDANCE AND CONTROL COMPONENTS RESEARCH, National Aeronautics and Space Administration - University Conference on Science and Technology of Space Exploration - Proceedings, Vol. 1, November 1962, pp. 387-394.

Paper examines research and development efforts on advanced spacecraft guidance and control components and systems; difficulties encountered in system design due to neglecting characteristics of real hardware are noted as well as constraints imposed on component development when tied to space programs; and role of universities and contributions made to field.

76. Frasier, C. W. and Gardiner, R. A.,
LUNAR EXCURSION MODULE MISSION AND RELATED GUIDANCE AND CONTROL FUNCTIONS, AIAA/ION Guidance and Control Conference, Minneapolis, Minnesota, 16-18 August 1965, A66-10001 01-21, New York, American Institute of Aeronautics and Astronautics, 1965, pp. 409-415, A66-10043.

The lunar excursion module (LEM) navigation, guidance, and control systems are developed from the overall mission

requirements and the basic system development ground rules. The role of the CSM equipment is included, in addition to that of the LEM. In general, the systems are described very briefly and the emphasis is placed upon the configuration which has evolved to meet the Apollo lunar orbit rendezvous requirements. The system configurations are also discussed from a reliability point of view. In addition to the present design, the potential role of optical systems in the LEM vehicle is briefly reviewed.

77. Frye, W. E.,
ON USE OF PRECISION FREQUENCY SIGNALS IN SPACE, Journal of Astronautical Sciences, Vol. 9, No. 1, Spring 1962, pp. 18-21.

Advent of very stable and accurate frequency sources and development of means for improving receiver sensitivity led to use of such devices as aid to navigation and guidance in many missions; features of radio navigation aid for lunar and interplanetary missions which employ precision accuracy sources and fixed antenna beams; and configuration using Earth and planetary satellites is proposed.

78. Funk, J.,
PROBLEMS IN SPACE NAVIGATION AND GUIDANCE, Manned Spacecraft - Engineering Design and Operation, New York, Fairchild Publications, Inc., 1964, pp. 223-231, A65-12552.

Included is a discussion of operations and techniques used to solve various spacecraft navigation and guidance problems. The Encke method for calculating flight-paths is described, as are a technique for evaluating the spacecraft state vector, and Battin's method for determining the flight-path error. As an example, the accuracy of midcourse navigation for a Mars mission is examined. Techniques for calculating required velocity corrections to the state vector are presented.

79. Gates, C. R. and Cutting, E.,
MIDCOURSE GUIDANCE USING RADIO TECHNIQUES,
Astronautics and Aeronautics, Vol. 10, 1963, pp. 265-278.

Lunar midcourse guidance using Earth-based radio tracking and computation is discussed; primary emphasis is on engineering factors, including requirements placed on spacecraft, tracking stations, and computing facilities; and performance, maneuver size, number of maneuvers, tracking accuracy, and guidance accuracy are treated.

80. General Dynamics/Astronautics,
LUNAR VEHICLE GUIDANCE STUDY - FINAL REPORT by R. Frimtzis, March 1962, GD/Astronautics AE 61-1241, (AD 273 301) (Unclassified).

The results of a study of lunar vehicle guidance are presented. Objectives of this study were to select and investigate trajectories for manned circumlunar flights, and to select and investigate trajectories and compatible guidance concepts for manned moon-to-Earth flights. Both coplanar and non-coplanar ballistic circumlunar trajectories were obtained and studied. Launch and injection characteristics for both trans-lunar and trans-Earth flights were analyzed and a guidance concept for take-off and midcourse corrections ascertained.

81. General Dynamics/Astronautics,
PRECISE LONG RANGE RADAR DISTANCE MEASURING TECHNIQUES by C. K. Rutledge, 13 February 1961, GD/Astronautics AE 61-0061 (Unclassified).

An analytical investigation of 200- to 3000-nautical-mile baseline radio tracking systems was conducted. The evaluation considered the use of the systems in tracking and guiding Earth satellites and lunar spacecraft. Representative error models for several tracking systems were formulated and compared. The comparison showed that systems which measure slant range only, contain fewer sources of error. A tracking system simulation employing computer programs and a high-speed digital computer is described.

82. General Electric Co.,
A STUDY OF MOTION NEAR LIBRATION POINTS IN THE EARTH-MOON SYSTEM by J. P. DeVries, January 1962, GE 62SD5 (Unclassified).

Not abstracted.

83. General Electric Co.,
ELECTRONICS EVALUATION STUDY (SPACE), FINAL REPORT (U), July 1965, GE Report No. 13416-C, TIL: 23076 (Secret).

CONTENTS

Space Vehicles

Guidance Systems

Telemetry

Electronics

84. General Motors Corporation, AC Spark Plug Division, Milwaukee, Wisconsin,
EXTENDED APOLLO SYSTEMS UTILIZATION STUDY, VOLUME 14, GUIDANCE AND NAVIGATION, FINAL REPORT (U), 16 November 1964, SID-64-1860-14, NASA-CR-60659, X65-12274 (Confidential).

Not abstracted.

85. George, T. S.,
COMMAND GUIDANCE OF AEROSPACE VEHICLES, Winter Institute on Advanced Control, Third, Space Vehicle Guidance and Control, Gainesville, Florida, 15-19 February 1965, Proceedings, A65-19051 09-21, Gainesville, Florida, University of Florida, Department of Electrical Engineering, 1965, 20 pp., A65-19062.

Included is a discussion of command guidance problems occurring in the initial powered-flight phase of missiles or space boosters and in interplanetary or deep spaceflight. Tracking during powered flight is generally accomplished by single-station pulse radars (which can employ Doppler techniques) or CW interferometric systems (such as Minitrack and Azusa). The range and angle accuracy obtainable with these systems is covered, and brief expositions on

phase-lock-loop systems and computation and control are included. For guidance at long ranges (over the 60, 000, 000-km distance to Venus, for example), CW systems with phase-lock loops are used for coherent filtering, demodulating, frequency multiplying, and frequency translating. The JPL Deep Space Instrumentation Facility system is described; it uses an 85-foot dish-type antenna to transmit an 890-Mc carrier signal to interrogate and control a satellite in deep space.

86. Gillespie, R. W., A SYSTEMATIC APPROACH TO THE STUDY OF STOPOVER INTERPLANETARY ROUND TRIPS, American Astronautical Society, Annual Meeting, 9th, Los Angeles, California, 15-17 January 1963, Advances in the Astronautical Sciences, Vol. 13, North Hollywood, California, Western Periodicals Co., 1963, pp. 165-176, A63-23392.

Included is a presentation of a list of trajectory data, including speeds, directions, and departure and arrival dates, for stopover round trips to Mars and Venus between 1960 and 1999. All data are calculated for the inclined, eccentric orbits. Use of the data to design rockets and plan expeditions is explained. Sample plans are described. A spectrum of expedition requirements is given, with suggestions for setting up a comprehensive space program.

87. Gold, T., QUICKENED MANUAL FLIGHT CONTROL WITH EXTERNAL VISUAL GUIDANCE, IEEE Transactions on Aerospace and Navigational Electronics, Vol. ANE-11, No. 3, September 1964, pp. 151-156.

Included are techniques for enhancing visual flight control by using quickening concepts: (1) pilot receives both guidance and flight-control information from relative positions of projected virtual images appearing through windshield and landmarks; (2) vehicle may then be controlled to couple preselected flight path in space terminating on landmark; (3) this is accomplished in continuous control task in which pilot tracks landmark with director image; and (4) first-, second-, and third-order quickened control systems are analyzed from dynamic standpoint.

88. Gordon, H. J. and Michel, J. R., MIDCOURSE GUIDANCE FOR MARINER MARS 1964, American Institute of Aeronautics and Astronautics, Annual Meeting, 2nd, San Francisco, California, 26-29 July 1965, Paper 65-402, A65-28880.

Included is a discussion of the preflight analysis, real-time execution, and results of the midcourse guidance for the Mariner Mars 1964 space probe. It is thought that a post-encounter maneuver is feasible and desirable after all the mission objectives have been satisfied.

89. Great Britain Office of Naval Research, London, England, THIRD EUROPEAN SPACE FLIGHT SYMPOSIUM, STUTTGART, 21-24 MAY 1963 by R. E. Adler, June 1963, 16 p., ONRL C10 63, AD-409 837 (Unclassified).

This meeting was the third annual symposium sponsored jointly by the German, French, and English Rocket Societies to stimulate space research in Europe by cooperation between European countries and collaboration with European industry. The contributed papers, the majority of which were given by Germany, covered the areas of general problems of space research, chemical rocket engines, sounding rockets, navigation, communication and guidance, space medicine astrobiology, space vehicles, satellites, electrical propulsion systems, attitude control of missiles, nuclear propulsion, and energy supply. The member rocket societies sponsoring the meeting were Deutsche Gesellschaft fur Raketentechnik und Raumfahrt (DGRR), societe Francaise D'astronautique (SFA), and the British Interplanetary Society (BIS). DGRR was the host society.

90. Green, J. S., REMOTE CONTROL OF SPACE VEHICLES, ISA Journal, Vol. 10, No. 3, March 1963, pp. 71-72.

Basic methods of control are reviewed from point of view of their adequacy for challenges ahead, performance criteria, command systems, control feedback telemetry, data link problems, and operations.

91. Grubin, C.,
DOCKING DYNAMICS FOR RIGID-BODY SPACECRAFT, AIAA Journal. Vol. 2, January 1964, pp. 5-12.

Not abstracted.

92. Gunckel, T. L., II,
EXPLICIT RENDEZVOUS GUIDANCE MECHANIZATION, Journal of Spacecraft and Rockets, Vol. 1, March-April 1964, pp. 217-219, A64-16897.

Included is a presentation of a set of guidance equations for a rendezvous vehicle based on an exact solution of the equations of motion of the vehicle. The rendezvous is accomplished in two thrusting periods: injection into the rendezvous trajectory, and nulling the closing velocity. By selecting the time of rendezvous, a free-fall trajectory may be determined which starts at the present position of the vehicle and passes through the rendezvous point at the designated time. The velocity vector necessary to achieve the free-fall trajectory that passes between two points in space in a given time increment is determined. The technique developed has been tested by simulating the conditions of lunar rendezvous after ascent from the surface of the moon, using a 90-degree transfer orbit. The simulation included the steering equations and flight controls dynamics, and was intended to approximate the actual behavior of the vehicle. Data are presented on the guidance accuracy for different time increments between velocity corrections.

93. Haberman, W.,
COMMAND AND CONTROL OF SPACE SYSTEMS, Missiles and Space, Vol. 8, No. 7, 8 July-August 1962, pp. 12-15.

Major elements which form command and control system are information gathering, information processing, communication, decision making, and direction of personnel and tools necessary to attain desired goal; command and control of space vehicles is currently handled by Air Force Satellite Control Facility, and National Aeronautics Space Administration Goddard Space Flight Center with its Minitrack Net and Mercury Control Net; tasks performed; and future requirements, orbital rendezvous, and docking maneuver.

94. Hailey, W. C., Mosner, P., and Vandervelde, W. E., PRECURSOR ORBITAL GUIDANCE, American Institute of Aeronautics and Astronautics, Guidance and Control Conference, Cambridge, Massachusetts, 12-14 August 1963, Paper, 16 pp., A63-21591.

Included is a description of the precursor system in the context of its operational environment. The system may facilitate the employment of atmospheric braking to attain an orbit about a planet as the terminal phase of an interplanetary trajectory. The role of aerodynamic braking in attainment of a planetocentric orbit is briefly described. In describing the precursor system, the required initial condition information, the means for deployment, the type and amount of information relayed back to the spacecraft, and the means of processing these data into the spacecraft velocity correction are discussed. A preliminary estimate is given of the space and weight requirements for the system and the propulsion requirement for the establishment of a prescribed orbit after the atmospheric pass. The results of an error analysis of the system which indicates concept feasibility are presented.

95. Haynes, N. R., et al, MARINER 4 FLIGHT PATH TO MARS, Astronautics and Aeronautics, Vol. 3, June 1965, pp. 28-33.

Not abstracted.

96. Heartz, R. A. and Jones, T. H., HYBRID SIMULATION OF SPACE VEHICLE GUIDANCE SYSTEMS, IEEE International Space Electronics Symposium-Recorded 6-9 October 1964, Paper 5-c, 12 pp.

Included is a hybrid simulation of guidance systems of space vehicles (specifically of lunar landing guidance systems) using analog and digital computers. Analysis has proved to be valuable in design reliability assessment, checkout, and training functions.

97. Hovorka, J.,
STATE OF ART OF INERTIAL DEVICES IN SPACE, ISA Proceedings, Preprint 33.1.62 for meeting 15-18 October 1962, 5 pp.

Included is the use of stable platforms, body-mounting of inertial instruments, and digital accelerometers and the use of pendulous integrating gyro units to replace inertial gyros in midcourse.

98. Institute of Radio Engineers, New York City, New York,
INERTIAL TECHNIQUES FOR NAVIGATION AND GUIDANCE, IRE National Aerospace Electronics Conference-Proceedings of 1962; "Searching Out New Inertial Guidance Techniques" by H. J. Chyba, pp. 548-552; "Spinning Fluid Gyro" by M. Wildman, pp. 553-561; "Timed Cut-Off Technique for Fast Inertial System Alignment on Accelerating Base" by E. R. Norman and D. J. Hafner, pp. 562-569; "Analysis and Evaluation of Proposed Method for Inertial Reentry Guidance of Deep Space Vehicle" by F. W. Chapman and P. J. Moonan, pp. 579-586; "Guidance of Sustained-High-Thrust, Super-Ballistic Space Craft" by C. W. Benfield, pp. 587-593.

Not abstracted.

99. Institute of Science and Technology, Michigan University,
SPACE GUIDANCE SCIENTIFIC SUPPORT STUDY (U) by R. Cheng, March 1964, RADC TDR 63-541 (Secret).

This report presents several aspects of a program designed to investigate the feasibility of utilizing surface-based electromagnetic radiation techniques in the guidance of space vehicles. Results of the first quarter of study are summarized and the status at that point is given. An analysis of a typical mission is given. This in turn produced numerical characteristics relative to the vehicle's velocity, attitude and position along the orbit.

100. International Telephone and Telegraph Corporation, LUNAR TERMINAL GUIDANCE TECHNIQUES STUDY, FINAL REPORT, VOLUME I (U), October 1959, ITT Corp 6032-FR-Oct 59, (AD-313 404), Contract AF 33(616)-6032 (Confidential).

This is the final report on the Lunar Terminal Guidance Techniques Studies for the period from 1 July 1958 to 30 October 1959. There were two main phases or efforts to the program. One of these was an analysis phase in which guidance equations were derived and performance specifications for particular missions were determined. The second phase was a techniques phase in which various guidance techniques were evaluated and a system was developed which will meet the performance requirements as established in the analysis phase. In this report, the analysis phase is concerned with a landing on the moon under conditions of velocity control only and with the problem of steering the vehicle to a particular landing site.

101. International Telephone and Telegraph Corporation, LUNAR TERMINAL GUIDANCE TECHNIQUES STUDY, FINAL REPORT, VOLUME II (U), October 1959, ITT Corp 6032-FR-Oct 59, (AD-313 405), Contract AF 33(616)-6032 (Confidential).

The problem of guiding the space vehicle to a particular location from a nearly vertical midcourse trajectory has been attacked by considering the following dictates: (1) low landing velocities; (2) landing at desired impact points; (3) velocity vector normal at impact; (4) proximity guidance is desirable (capability of making last instant maneuvers to avoid undesirable terrain features); (5) minimum braking energy; (6) allowable tolerances on midcourse guidance; and (7) many other considerations applicable in special cases, which are dictated by the instrumentational or operational realities.

102. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, ANALYSIS OF RADIO-COMMAND MIDCOURSE GUIDANCE by A. R. M. Noton, E. Cutting, and F. L. Barnes, 8 September 1960, JPL TR-32-28, Contract NASw-6 (Unclassified).

The injection or ascent guidance systems that will be used for space vehicles in the next few years will not have sufficient accuracy for advanced lunar or interplanetary missions. It will be necessary to have some form of midcourse guidance in

order to reduce terminal dispersions. This report is concerned with a specific midcourse guidance scheme which utilizes a small rocket motor mounted on the spacecraft for small impulse-type corrections. The report first developed the mathematical theory of midcourse guidance. Terminal coordinates are discussed, the concept of the critical-plane is introduced, and the exact computation of the maneuver is covered in addition to the method of estimating the required amount of rocket propellant.

103. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California,
COMMAND TECHNIQUES FOR THE REMOTE CONTROL OF INTERPLANETARY SPACECRAFT by J. C. Springett, 1 August 1962, JPL TR-32-314, Contract NAS7-100 (Unclassified).

Information necessary to the success of a spacecraft mission through its various control systems, which cannot be obtained or "loaded into" the spacecraft prior to launch, requires that a suitable command link to the spacecraft be established to implement these functions. It is the purpose of this report to elaborate on the command system design and operation philosophy that will be employed for the Mariner series of spacecraft to be launched to Mars and Venus during 1962 to 1966. It is not intended to detail all systems comprising the command link.

104. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California,
CONTROL AND GUIDANCE OF ELECTRICALLY PROPELLED SPACECRAFT by P. J. Hirrel, 15 September 1961, JPL TR-32-166, Contract NASw-6 (Unclassified).

Some of the conditions and methods of control and guidance for a nuclear-electric spacecraft are discussed in general terms. The type of spacecraft considered is propelled by an ion motor. The broad aspects of the flight trajectory peculiar to this type of propulsion are examined. Some equipment limitations are reviewed.

105. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California,
GUIDANCE FOR SPACE MISSIONS by C. G. Pfeiffer, 12 June 1959, JPL Ext Pub 656, Contract NASw-6 (Unclassified).

The guidance problem consists of determining a corrective maneuver to be applied to a missile such that the desired mission will be accomplished. This report discusses some of the techniques currently being employed to study the guidance problem and will, therefore, be oriented toward missions which will be accomplished within the next few years.

106. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California,
GUIDANCE OF UNMANNED LUNAR AND INTERPLANETARY SPACECRAFT by C. G. Pfeiffer, JPL TR-32-472, N64-32824, Contract NAS7-100, Progr. Astron. Aeron. Vol. 14, 1964, pp. 259-281, AIAA Astrodyn. Conference, New Haven. Connecticut, 19-21 August 1963 (Unclassified).

This paper describes mathematical techniques that have been developed for accomplishing Earth-based guidance of unmanned lunar and interplanetary spacecraft. The orbit-determination and guidance-correction aspects of the problem are developed from linear perturbation techniques, well known in exterior ballistics problems. An expression for the effect of neglected second-order terms is developed. The treatment of correlated noise on the orbit determination data is discussed. Policies for determining when to perform impulsive guidance corrections to the orbit are described, and a technique for optimal guidance of powered flight trajectories is outlined.

107. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California,
INTERPLANETARY POST-INJECTION GUIDANCE by A. R. M. Noton, 4 June 1959, JPL Ext Pub 653, Contract NASw-6 (Unclassified).

Systems of midcourse and terminal guidance that might be applied to interplanetary missions in the next five years are considered. The necessary theoretical background is developed for the formation of guidance equations and for carrying out error analysis. Midcourse guidance both by radio command and with a celestial navigator is discussed, backed up by error analysis for special cases. The overall

accuracy of a radio-command system is estimated, and representative figures are derived to illustrate the goal of hardware development for celestial navigators. Terminal guidance prior to entry into planetary atmospheres is similarly discussed.

108. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California,
JUNO IV ROCKET VEHICLE SYSTEM (U) by J. D. Burke, D. R. Bartz, and A. Briglio, 27 December 1960, JPL 20-123, Contract NASw-6 (Confidential).

Not abstracted.

109. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California,
PLANETARY APPROACH GUIDANCE by C. R. Gates and H. J. Gordon, 30 June 1964, JPL TR-32-631, NASA CR-58236, N64-29004, Contract NAS7-100 (Unclassified).

Planetary approach guidance, an onboard optical guidance system for a planet-bound spacecraft, functions as the spacecraft approaches the target planet. Such a system should attain an accuracy greater than that obtainable from Earth-based radio guidance. The need for planetary approach guidance is discussed, a set of orbital parameters especially developed for the problem is presented, and analytic differential corrections are derived. Covariance matrices for orbital parameters are given. A specific mechanization is discussed, measurement errors are described, and parametric curves showing accuracy are presented.

110. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California,
SIMPLE GUIDANCE FOR DEEP-SPACE BOOSTER VEHICLES by C. G. Pfeiffer, November 1961, JPL TR-32-128, Contract NAS2-6 (Unclassified).

A relatively simple injection-guidance system used in conjunction with post-injection midcourse correction will be adequate for lunar and interplanetary missions. Results of a JPL study are presented to demonstrate the adequacy of a simple guidance scheme. It is shown that the use of a simple system requires additional midcourse propellant in an amount less than one percent of the spacecraft weight, a small penalty in terms of other gains through guidance simplicity.

111. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California,
THE DEEP SPACE NETWORK FOR THE PERIOD 1 MAY - 30 JUNE 1964, 31 July 1964, JPL-SPS-37-28, Vol. III, NASA-CR-58556, N64-29356, Contract NAS7-100 (Unclassified).

The deep space network (DSN) is a precision communication system that is designed to communicate with, and permit control of, spacecraft designed for deep-space exploration. The DSN consists of the deep space instrumentation facility (DSIF), the space flight operations facility (SFOF), and the DSN ground communication system (GCS). This report discusses the following areas relative to the DSN: (1) tracking station engineering and operations; (2) efforts of the SFOF operations group in support of Ranger and Mariner tests; (3) the development of the Goldstone duplicate standard 1964 model S-band RF system, with emphasis on a functional description of the S-band receiver, transmitter, and antenna microwave subsystem; (4) communications engineering developments-S-band implementation for DSIF and Mariner C transmitter development; (5) communications research and development-ground antennas. Venus site experimental activities, the S-band and X-band lunar-planetary radar projects, and the development of digital circuit modules; and (6) the state-of-the-art of the 210-foot-diameter advanced antenna system for the Mars site of the Goldstone tracking station.

112. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California,
THE DEEP SPACE NETWORK FOR THE PERIOD 1 SEPTEMBER TO 31 OCTOBER 1964 by W. H. Pickering, 30 November 1964, JPL-SPS-37-30, NASA-CR-59913, N65-13299, Contract NAS7-100 (Unclassified).

The deep space network (DSN) is a precision communication system that is designed to communicate with, and permit control of, spacecraft designed for deep space exploration. The DSN has facilities for simultaneously controlling a newly launched spacecraft and one already in flight. The Deep Space Instrumentation Facility section of DSN utilizes large antennas, low-noise phase-lock receiving systems, and high-power transmitters located at stations positioned at approximately 120-degree intervals around the Earth. Discussed in the report on DSN activities are the following subjects: tracking station engineering and operations, space-flight operations, radio-

frequency systems, communications engineering, communications development and research, and advanced antennas.

113. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California,
DEEP SPACE NETWORK FOR THE PERIOD 1 JANUARY TO 2 FEBRUARY 1965, VOLUME III by W. H. Pickering, 31 March 1965, JPL-SPS-37-32, NASA CR-62609, N65-23282, Contract NAS7-100 (Unclassified).

A precision communication system designed to communicate with, and permit control of, spacecraft designed for deep space exploration is discussed. Major subjects covered are tracking stations engineering and operations, communications engineering developments, communications research and development, and advanced antenna systems. Further, the mission, organization, and capabilities of the network are also discussed.

114. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California,
THE DEEP SPACE NETWORK, VOLUME III, 31 May 1964, JPL-SPS-37-27, NASA CR-56786, N64-25676, Contract NAS7-100 (Unclassified).

The Deep Space Network (DSN) is a precision communication system designed to communicate with, and permit control of, spacecraft designed for deep space exploration. The following topics related to DSN are discussed: (1) tracking stations engineering and operations, (2) space flight operations facility, (3) DSN ground communication system, (4) communications engineering developments, (5) communications research and development, and (6) an advanced antenna system.

115. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California,
THE PLANETARY-INTERPLANETARY PROGRAM, VOLUME II (U), 31 May 1962, JPL-SPS-37-15, Contract NAS7-100 (Confidential).

Not abstracted.

116. Keller, G. R.,
FLIGHT CONTROL OF AEROSPACE VEHICLES, Hydraulics and Pneumatics, Vol. 14, December 1961, pp. 68-69.

Not abstracted.

117. Kochi, K. C. and Dibble, H. L.,
STELLAR TECHNIQUES FOR MIDCOURSE NAVIGATION-GUIDANCE, American Institute of Aeronautics and Astronautics, Guidance and Control Conference, Cambridge, Massachusetts, 12-14 August 1963, Paper 63-357, 46 pp., A63-21695.

Preliminary survey of sensing and mechanization computation techniques for solving the midcourse phase of the navigation-guidance problem aboard the spacecraft. Only those techniques associated with optical-inertial systems are emphasized because they appear to typify the truly self-contained concept for manned deep-space applications. Particularly considered are the data-gathering, computational, and data-processing techniques for handling attitude determination, trajectory determination (navigation), and trajectory control (guidance) computational problems. The midcourse phase is assumed to begin at the end of vernier control of the ascent-boost phase when the spacecraft goes into the free-fall condition. To bring the overall midcourse navigation-guidance problem into proper perspective, a brief account is given of various integrated systems concepts and operational procedures. Emphasis is placed on minimal systems concepts capable of solving the complete midcourse problem.

118. Kopp, R. E. and Orford, R. J.,
LINEAR REGRESSION APPLIED TO SYSTEM IDENTIFICATION FOR ADAPTIVE CONTROL SYSTEMS, AIAA Journal, Vol. 1, October 1963, pp. 2300-2306.

Not abstracted.

119. Kraft, C. C., Jr.; Hodge, J. D.; and Kranz, E. F.,
MISSION CONTROL FOR MANNED SPACE FLIGHT, AIAA-2nd Manned Space Flight Meeting-Technical Papers, 22-24 April 1963, pp. 199-205.

This paper reviews growth of flight control for Project Mercury, Gemini, and Apollo; Integrated Mission Control

Center facility in Houston, Texas includes internal and external computing facilities, communications facilities, network stations and flight control teams, launch facilities, and spacecraft and flight crew, and significant portions of Gemini mission which detail flight control operations for both manned spacecraft and unmanned flight vehicles are presented.

120. Kramer, M.,
APOLLO COMMAND MODULE AND LEM GUIDANCE AND NAVIGATION SYSTEMS, Society of Automotive Engineers, Paper SP-257, October 1964, pp. 29-35 and 62.

This paper presents functional description of onboard Apollo command module and lunar excursion module guidance and navigation equipments and illustrates how combinations of each can be employed to instrument Apollo mission phases; midcourse navigation techniques are described, making reference to all parameters which constitute limits on navigational accuracy; and complete mission profile is presented and roles of each major subsystem are described for specific mission phases.

121. Kramer, M.,
APOLLO COMMAND MODULE AND LEM GUIDANCE AND NAVIGATION SYSTEMS, Apollo - A Program Review; Society of Automotive Engineers, National Aeronautic and Space Engineering and Manufacturing Meeting, Los Angeles, California, 5-9 October 1964, Proceedings (SP-257), New York, Society of Automotive Engineers, Inc., 1964, pp. 29-35 and 62, A65-12734.

Included is a functional description of the guidance and navigation equipment used by both the Apollo command service module (CSM) and lunar excursion module (LEM). It is shown how combinations of each can be used to implement Apollo mission phases. Coupling units between major subsystems are briefly referred to. They make possible inference of the limitations of data transfer and, hence, correlation with system accuracy. Midcourse navigation techniques are described, making reference to all parameters which constitute limits on navigational accuracy. A complete mission profile is presented and the roles of each major subsystem are described for specific mission phases.

122. Kriegsman, B. A. and Reiss, M. H.,
TERMINAL GUIDANCE AND CONTROL TECHNIQUES FOR SOFT LUNAR LANDING, ARS Journal, Vol. 32, March 1962, pp. 401-413.

Not abstracted.

123. LaBerge, W. B.,
PROJECT APOLLO'S COMMAND AND CONTROL, Electronic Industries, Vol. 22, July 1963, pp. 58-60.

Not abstracted.

124. Lally, E.,
FLEXIBLE GUIDANCE NEEDED FOR SOFT PLANET LANDINGS, Space/Aeronautics, Vol. 35, April 1961, pp. 137-138.

Not abstracted.

125. Langford, R. C.,
GUIDANCE AND CONTROL, Astronautics and Aerospace, Vol. 1, No. 10, November 1963, pp. 114-117.

Survey of state-of-art advances in guidance and control theory shows steady progress in developing techniques for torquing body being controlled, including use of reaction wheels, fluid jets, despin magnets, solar sails, ion engines, exploding wires, damping mechanisms, etc., to give spin stabilization and momentum storage; description of various attitude control systems; stellar inertial systems; and laser research establishing fundamental physical feasibility of laser optical gyro, however, considerable research and development will be required before practical instruments can be built.

126. Langford, R. C. and C. J. Mundo,
GUIDANCE AND CONTROL - II (PROGRESS IN ASTRONAUTICS AND AERONAUTICS, VOLUME 13), New York and London, Academic Press, 1964, 997 pp., A64-22868.

CONTENTS

127. No entry.

128. Legalley, D. P.,
GUIDANCE AND CONTROL, Astronautics, Vol. 7, November 1962, pp. 48-51, A63-10193.

Included is a review of the state-of-the-art of space-vehicle guidance and control, with emphasis on: (1) rendezvous and docking; (2) a guidance-evaluation missile that would test the performance of inertial systems and components, and stellar-inertial systems and components, under operating conditions; (3) research and development programs; and (4) exotic developments such as cryogenic gyros.

129. Leondes, C. T.,
GUIDANCE AND CONTROL OF AEROSPACE VEHICLES, New York, McGraw-Hill Book Co., Inc., 1963, 610 pp., A63-25911.

Included is a detailed treatment of terrestrial, satellite, and extra-terrestrial guidance and control systems. Fundamental techniques and typical results are presented for the various classes of guidance and control problems. The present state of development of systems in the research stage is outlined, as are the future developments. Discussed at length are the basic considerations involved in the quantitative evaluation of the relative merits of a variety of guidance and control techniques in their application to specific system missions. Specifically covered are such topics as guidance and control of missiles launched from moving vehicles, trajectory aspects of guidance, passive and active satellite attitude control, satellite terminal guidance and station keeping, orbital guidance systems and techniques, boost glide and reentry guidance and control, midcourse guidance and control, and lunar and interplanetary systems. The items are individually abstracted and indexed in this issue.

130. Leondes, C. T.,
INTRODUCTION TO THE GUIDANCE AND CONTROL OF AEROSPACE VEHICLES, Guidance and Control of Aerospace Vehicles, New York, McGraw-Hill Book Co., Inc., 1963, pp. 3-15, A63-25912.

Included is a discussion of the scope and definition of the guidance and control problem of an aerospace vehicle. Outlined are the approaches used in treating the following topics: (1) the trajectory aspects of guidance, (2) sensors for aerospace-vehicle guidance, (3) cruise guidance and control, (4) rocket and ICBM guidance and control, (5) guidance and control of missiles launched from moving vehicles, (6) passive satellite attitude control, (7) active satellite attitude control, (8) satellite terminal guidance and station keeping, (9) boost glide and reentry guidance and control, (10) midcourse guidance and control, and (11) lunar and planetary systems.

131. Lessing, H. C., Tunnell, P. J., and Coate, R. E.,
LUNAR LANDING AND LONG-RANGE EARTH REENTRY GUIDANCE BY APPLICATION OF PERTURBATION THEORY, Second Manned Space Flight Meeting, New York, American Institute of Aeronautics and Astronautics, 1963, pp. 140-150, A63-19001.

Included is an investigation of a guidance scheme which has as its basis linear perturbation theory. An improved capability of the scheme is achieved by the proper choice of independent variable and by appropriate weighting of the guidance gains computed on the basis of the linear theory. The capability of this guidance scheme applied to the descent-to-hover phase of lunar landing is demonstrated for two different types of nominal trajectory: a constant-thrust gravity turn maneuver, and a constant-thrust, constant-pitch-rate maneuver. For the purpose of demonstrating the performance of this type of guidance scheme for atmosphere entry, it is applied to the guidance of a vehicle entering the Earth's atmosphere at parabolic velocity. The guidance capability of this control scheme is evaluated for entries from abort conditions as well as for entries within the normal entry corridor. The effects upon the guidance capability of variations in lift-drag ratio and atmospheric density are investigated. It is shown that for both lunar landing and atmosphere entry, this

guidance system, which uses a single nominal trajectory, permits guidance to a selected landing site from a wide range of initial conditions. Since a single nominal trajectory is used, only minimum storage capacity is required.

132. Lichtenstein, B.,
TESTING OF STELLAR-INERTIAL GUIDANCE SYSTEMS, IEEE Transactions on Military Electronics, Vol. MIL-7, No. 1, January 1963, pp. 29-35.

Various types of stellar-inertial systems are discussed with emphasis on their differences so as to provide basis for meaningful test plans; effect of stellar-inertial measuring unit design, whether tracker possesses daylight capabilities or not, and differences between 1-star and 2-star systems are cited; and it is shown that flight testing must occur earlier in evaluation of stellar-inertial system than is necessary with pure inertial system.

133. Liebelt, P. B.,
MANUAL EXTRATERRESTRIAL GUIDANCE AND NAVIGATIONAL SYSTEM, AIAA Journal, Vol. 1, September 1963, pp. 2142-2144.

Not abstracted.

134. Lockheed Aircraft Corporation,
ANALYTICAL DETERMINATION OF THREE-DIMENSIONAL INTERPLANETARY TRANSFERS by D. N. Lascody, September 1962, LAC LR-16179 (Unclassified).

Not abstracted.

135. Lockheed Missiles and Space Co., Sunnyvale, California,
G + C SUBSYSTEM ENGINEERING ANALYSIS REPORT, AGENA VEHICLES 6006 THROUGH 6009 NASA RANGER PROGRAM by J. J. Kennelly, 1 September 1964, LMSC-A306612-A, NASA-CR-58726, X64-16388, Contract NAS3-3800 (Unclassified).

Not abstracted.

136. Lockheed Missiles and Space Co., Sunnyvale, California, THE OPTIMUM SPACING OF CORRECTIVE THRUSTS IN INTERPLANETARY NAVIGATION by J. V. Breakwell, April 1963, X63-14359, X63-14356 (Unclassified).

Not abstracted.

137. Loh, W. H. T., SOME EXACT ANALYTICAL SOLUTIONS OF PLANETARY ENTRY, AIAA Journal, Vol. 1, No. 4, April 1963, pp. 836-842.

This paper presents some exact analytical solutions obtained recently; when minor terms of exact solutions are neglected, exact solutions reduce precisely to those approximate solutions presented previously by author for variable lift-drag ratio entry; and solutions developed, such as approximate constant deceleration entry, are especially useful for proper entry into Jupiter, where entry deceleration is most critical.

138. Lyapunov, B. V., ROCKETS AND INTERPLANETARY FLIGHTS (Rakety i Mezhplanetnyye Polety) Translated into English from Russian by the Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, 11 June 1963, FTD-TT-63-210/1+2, AD-602559, N64-32398.

The evolution in the USSR of the idea of interplanetary travel is traced from Kibal'chich and Tsiolkovskiy to the early twentieth-century experimenters, such as Kondratyuk. The principles of rocketry and interplanetary flight guidance are discussed in nontechnical terms. Progress and accomplishments of Soviet rocket and space research are noted in detail, and the first flights in the Explorer and Vanguard series are mentioned. Laboratory experiments, trial satellite launchings, life-support system development, guidance and control system development, and other work necessary to successful manned space flight are described. The orbital flights of Vostok I and Vostok II are narrated in detail, and hazards of space flight are enumerated. A review of non-Russian design work on Earth-orbiting manned space stations is presented. Forecasts of future space accomplishments are given, and a chronology of Russian space achievements is presented.

139. Mallan, L.,
AGENA MAY OUTPERFORM GEMINI 6, Electronics, Vol. 38, 6 September 1965, pp. 113-115.

Not abstracted.

140. Markson, E. E.,
EXPLICIT GUIDANCE CONCEPT, AIAA Journal, Vol. 1, November 1963, pp. 2630-2631.

Not abstracted.

141. Martin, B. P.,
MANNED FLIGHT TO MARS AND VENUS IN THE 70's, Second Manned Space Flight Meeting, New York, American Institute of Aeronautics and Astronautics, 1963, pp. 236-253, A63-19014.

Velocity requirements, associated with various flight paths to Mars and Venus, and the resulting propulsion and reentry weights are combined and varied with other mission system weights which are a function of mission goals, trip time, and environmental protection. From these weight trade-off analyses there are evolved spacecraft design concepts and total mass requirements on Earth orbit to accomplish the various missions. Mass requirements, so established, are compared with launch rocket capabilities. System requirements described to determine total mass requirements for Earth orbit are: (1) propulsion systems for Earth-orbit departure; (2) Earth-entry systems for different missions; (3) life-support systems; (4) navigation and control systems; (5) reconnaissance and scientific instrumentation for gathering data during course of missions, and requirements for storage and/or readout; (6) space power supply systems; and (7) vehicle-design concepts.

142. Martin, B. P.,
MANNED INTERPLANETARY MISSIONS, Marshall Space Flight Center Proceedings of the Symposium on Manned Planetary Missions, 1963-1964 Status 12 June 1964, pp. 75-140, N64-26979, N64-26981, Contract NAS8-5024.

The following are discussed with respect to manned interplanetary missions: (1) missions - short stopovers on a satellite orbit, single-launch flyby trajectories passing both Mars

and Venus, and flybys passing only one planet; (2) Earth-orbit launch constraints - hyperbolic escapes; (3) crew utilization and requirements - ionizing radiation, physicochemical regeneration, and trace-contaminant control; (4) guidance and control injection into heliocentric trajectory, midcourse correction, planet approach, and stopover orbits; (5) reconnaissance - integrated systems of data sensing, processing, correlation, and evaluation; and (6) power systems - recommendation of from 20 to 200 megawatts for several seconds, without causing objectionable interference to their service to other customers. Evidence is presented that if these utility system characteristics are fully exploited, a substantial reduction in the cost of pulsed magnet power supplies can result.

143. Massachusetts Institute of Technology, Instrumentation Laboratory, Cambridge, Massachusetts,
FINAL REPORT ON LOW-THRUST VEHICLE GUIDANCE STUDY, VOLUME I, PART 1 by J. S. Miller, August 1961, MIT/IL R-333, Contract AF-04(647)-305 (Unclassified).

This report considers various aspects of the guidance of a low-thrust vehicle. Theory is the main topic discussed.

144. Massachusetts Institute of Technology, Instrumentation Laboratory, Cambridge, Massachusetts,
FINAL REPORT ON LOW-THRUST VEHICLE GUIDANCE STUDY, VOLUME II, PARTS 2 AND 3 by J. S. Miller, August 1961, MIT/IL R-333, Contract AF-04(647)-305 (Unclassified).

This report considers various aspects of the guidance of a low-thrust vehicle. It is divided into two parts: guidance system implementation and space sextant feasibility demonstration.

145. Massachusetts Institute of Technology, Instrumentation Laboratory, Cambridge, Massachusetts,
INERTIAL GUIDANCE-TERRESTRIAL AND INTERPLANETARY, VOLUME IV by M. B. Trageser, 15 July 1960, MIT/DAA 16, 45S (Unclassified).

The first part of this report is a paper on implementation of interplanetary guidance and control, in which a preliminary design for a 340-pound space probe which could implement the round trip interplanetary mission is presented. The

and Venus, and flybys passing only one planet; (2) Earth-orbit launch constraints - hyperbolic escapes; (3) crew utilization and requirements - ionizing radiation, physicochemical regeneration, and trace-contaminant control; (4) guidance and control injection into heliocentric trajectory, midcourse correction, planet approach, and stopover orbits; (5) reconnaissance - integrated systems of data sensing, processing, correlation, and evaluation; and (6) power systems - recommendation of from 20 to 200 megawatts for several seconds, without causing objectionable interference to their service to other custcmers. Evidence is presented that if these utility system characteristics are fully exploited, a substantial reduction in the cost of pulsed magnet power supplies can result.

143. Massachusetts Institute of Technology, Instrumentation Laboratory, Cambridge, Massachusetts,
FINAL REPORT ON LOW-THRUST VEHICLE GUIDANCE STUDY, VOLUME I, PART 1 by J. S. Miller, August 1961, MIT/IL R-333, Contract AF-04(647)-305 (Unclassified).

This report considers various aspects of the guidance of a low-thrust vehicle. Theory is the main topic discussed.

144. Massachusetts Institute of Technology, Instrumentation Laboratory, Cambridge, Massachusetts,
FINAL REPORT ON LOW-THRUST VEHICLE GUIDANCE STUDY, VOLUME II, PARTS 2 AND 3 by J. S. Miller, August 1961, MIT/IL R-333, Contract AF-04(647)-305 (Unclassified).

This report considers various aspects of the guidance of a low-thrust vehicle. It is divided into two parts: guidance system implementation and space sextant feasibility demonstration.

145. Massachusetts Institute of Technology, Instrumentation Laboratory, Cambridge, Massachusetts,
INERTIAL GUIDANCE-TERRESTRIAL AND INTERPLANETARY, VOLUME IV by M. B. Trageser, 15 July 1960, MIT/DAA 16, 45S (Unclassified).

The first part of this report is a paper on implementation of interplanetary guidance and control, in which a preliminary design for a 340-pound space probe which could implement the round trip interplanetary mission is presented. The

discussion emphasizes the guidance and control aspects of the probe. The second part (The Stable Platform - Geometric Stabilization and Orientation Control) discusses the design of the stable platform. Studies on dynamics of gyroscopic instruments and gear training dynamics appear in appendices.

146. Massachusetts Institute of Technology, Instrumentation Laboratory, Cambridge, Massachusetts,
LEM TRUCK GUIDANCE AND NAVIGATION STUDY FINAL REPORT, 14 AUGUST 1964 - 28 FEBRUARY 1965 by B. M. Hildebrant, 28 February 1965, X65-13991, NSR-22-009-068, NASA-CR-57763 R-487 (Unclassified).

Not abstracted.

147. Massachusetts Institute of Technology, Instrumentation Laboratory, Cambridge, Massachusetts,
PROJECT APOLLO GUIDANCE AND NAVIGATION PROGRAM, MONTHLY TECHNICAL PROGRESS REPORT, 11 DECEMBER 1961 TO 16 JANUARY 1962 (U) by M. B. Trageser and R. B. Woodbury, 1962, X63-10924, Contract NAS9-153/E-1117 (Confidential).

Not abstracted.

148. Massachusetts Institute of Technology, Instrumentation Laboratory, Cambridge, Massachusetts,
PROJECT APOLLO GUIDANCE AND NAVIGATION PROGRAM, MONTHLY TECHNICAL PROGRESS REPORT, 11 APRIL 1962 TO 1 MAY 1962 (U) by M. B. Trageser and R. B. Woodbury, 1962, X63-10927, Contract NAS9-153/E-1177 (Confidential).

Not abstracted.

149. Massachusetts Institute of Technology, Instrumentation Laboratory, Cambridge, Massachusetts,
PROJECT APOLLO GUIDANCE AND NAVIGATION PROGRAM, QUARTERLY TECHNICAL PROGRESS REPORT, PERIOD ENDED 11 MARCH 1962 (U) by M. B. Trageser et al, June 1962, X63-11854, Contract NAS9-153/E-1140 (Confidential).

Not abstracted.

150. Massachusetts Institute of Technology, Instrumentation Laboratory, Cambridge, Massachusetts,
PROJECT APOLLO GUIDANCE AND NAVIGATION PROGRAM, QUARTERLY TECHNICAL PROGRESS REPORT, 11 JUNE 1962 (U), 1962, X63-16927, Contract NAS9-153/NASA-CR-52107/E-1199 (Confidential).

Not abstracted.

151. Massachusetts Institute of Technology, Instrumentation Laboratory, Cambridge, Massachusetts,
APOLLO GUIDANCE AND NAVIGATION, GUIDANCE AND NAVIGATION SYSTEM FOR LUNAR EXCURSION MODULE (U) by J. M. Dahlen, P. G. Felleman, R. D. Goss, N. E. Sears, M. B. Trageser, and R. L. White, July 1962, X63-10922, Contract NAS9-153/R-373 (Confidential).

Not abstracted.

152. Massachusetts Institute of Technology, Instrumentation Laboratory, Cambridge, Massachusetts,
APOLLO GUIDANCE AND NAVIGATION, GUIDANCE AND NAVIGATION SYSTEM FOR LUNAR EXCURSION MODULE (U) by J. M. Dahlen, P. G. Felleman, R. D. Goss, N. E. Sears, M. B. Trageser, and R. L. White, August 1962, X63-10923, Contract NAS9-153/R-373/Rev A (Confidential).

Not abstracted.

153. Massachusetts Institute of Technology, Instrumentation Laboratory, Cambridge, Massachusetts,
PROJECT APOLLO GUIDANCE AND NAVIGATION PROGRAM, QUARTERLY TECHNICAL PROGRESS REPORT, PERIOD ENDED 11 SEPTEMBER 1962 (U) by M. B. Trageser, February 1963, X63-11855, Contract NAS9-153/E-1238 (Confidential).

Not abstracted.

154. Massachusetts Institute of Technology, Instrumentation Laboratory, Cambridge, Massachusetts,
PROJECT APOLLO GUIDANCE AND NAVIGATION PROGRAM, MONTHLY TECHNICAL PROGRESS REPORT, PERIOD 11 OCTOBER 1962-13 NOVEMBER 1962 (U) by M. B. Trageser, March 1963, X63-11856, Contract NAS9-153/E-1303 (Confidential).

Not abstracted.

155. Massachusetts Institute of Technology, Instrumentation Laboratory, Cambridge, Massachusetts,
APOLLO GUIDANCE AND NAVIGATION, APOLLO MIDCOURSE GUIDANCE (U) by J. W. Hursh, November 1962, X63-10928, Contract NAS9-153/E-1256 (Confidential).

Not abstracted.

156. Massachusetts Institute of Technology, Instrumentation Laboratory, Cambridge, Massachusetts,
APOLLO GUIDANCE AND NAVIGATION, A PROGRESS REPORT ON THE APOLLO GUIDANCE SYSTEM (U) by D. Hoag and M. B. Trageser, December 1962, X63-11787, Contract NAS9-153, DSR Proj. 55-191/R-388 (Confidential).

Not abstracted.

157. Massachusetts Institute of Technology, Instrumentation Laboratory, Cambridge, Massachusetts,
APOLLO GUIDANCE AND NAVIGATION, MASSACHUSETTS INSTITUTE OF TECHNOLOGY SPACE IMPLEMENTATION INTERIM REPORT by G. R. Gilbert, January 1963, X63-16113, Contract NAS9-153/NASA-CR-51220, E-1278 (Unclassified).

Not abstracted.

158. Massachusetts Institute of Technology, Instrumentation Laboratory, Cambridge, Massachusetts,
APOLLO GUIDANCE AND NAVIGATION SYSTEM RELIABILITY APPORTIONMENTS AND INITIAL ANALYSIS (U) by G. W. Mayo, Jr., and G. E. Kruszewski, February 1963, X63-11779, Contract NAS9-153, DSR Proj. 55-191/R-395 (Confidential).

Not abstracted.

159. Massachusetts Institute of Technology, Instrumentation Laboratory, Cambridge, Massachusetts,
APOLLO GUIDANCE AND NAVIGATION PROGRAM, QUARTERLY TECHNICAL PROGRESS REPORT, MARCH 1963 (U), 1963, X63-16928, Contract NAS9-153/NASA-CR-52113, E-1307 (Confidential).

Not abstracted.

160. Massachusetts Institute of Technology, Instrumentation Laboratory, Cambridge, Massachusetts,
APOLLO GUIDANCE AND NAVIGATION - SYSTEM STATUS REPORT (U) by M. B. Trageser and R. B. Woodbury, August 1963, X64-10390, Contract NAS9-153/NASA-CR-52277, E-1142/Rev 11 (Confidential).

Not abstracted.

161. Massachusetts Institute of Technology, Instrumentation Laboratory, Cambridge, Massachusetts,
SPACE VEHICLE GUIDANCE INVESTIGATIONS EXPLORATORY DEVELOPMENT PROGRAM, VOLUME I, PART A - INTRODUCTION, PART B - MISSION NAVIGATION AND GUIDANCE STUDIES, FINAL TECHNICAL REPORT, 10 JANUARY-31 OCTOBER 1964 (U) by T. M. Alexander, Jr., 10 November 1964, SSD-TR-64-296, R-473, AD-355186, X65-11451, Contract AF-04(695)-290 (Secret).

Not abstracted.

162. Massachusetts Institute of Technology, Instrumentation Laboratory, Cambridge, Massachusetts,
SPACE VEHICLE GUIDANCE INVESTIGATIONS EXPLORATORY DEVELOPMENT PROGRAM, VOLUME I, PART A - INTRODUCTION, PART B - MISSION GUIDANCE AND CONTROL STUDIES, TECHNICAL DOCUMENTARY REPORT, 10 JANUARY 1963-10 JANUARY 1964 (U) by W. R. Blackwood, 10 February 1964, SSD-TDR-64-63, Vol. 1, AD-351042, X64-16692, Contract AF-04(695)-290 (Secret).

Not abstracted.

163. Massachusetts Institute of Technology, Instrumentation Laboratory, Cambridge, Massachusetts,
SPACE VEHICLE GUIDANCE INVESTIGATIONS EXPLORATORY DEVELOPMENT PROGRAM, VOLUME II, PART C - INSTRUMENTATION RESEARCH AND DEVELOPMENT, TECHNICAL DOCUMENTARY REPORT, 10 JANUARY 1963, 10 JANUARY 1964 (U) by W. R. Blackwood, 10 February 1964, SSD-TDR-64-63, Vol. 2, AD-351043, X64-16693, Contract AF-04(695)-290 (Secret).

Not abstracted.

164. Matthews, M. A. V.,
INERTIAL SYSTEMS IN SPACE VEHICLES, British Institute of Radio Engineers Journal, Vol. 22, No. 3, September 1961, pp. 231-239.

Use of inertial elements in space vehicles for attitude control and navigation is discussed. Although not often capable of performing these functions by itself, inertial system used in conjunction with other elements can allow design of other instruments to be simplified.

165. Miner, W. E. and Schm 'er, D. H.,
THE PATH-ADAPTIVE MODE FOR GUIDING SPACE FLIGHT VEHICLES, American Rocket Society, 9 August 1961, ARS Reprint 1944-61, 6 pp.

This paper was presented at the Guidance, Control, and Navigation Conference 7-9 August 1961, at Stanford University. The need for a more flexible guidance mode than the types now commonly known is established as growing out of requirements imposed by large staged and clustered space flight vehicles. A new guidance mode is then developed which meets these requirements. The steering function, which is the heart of this Path-Adaptive Mode, is derived in general terms. A concluding description is given of the principal features of the mode.

166. Mitchell, E. D.,
GUIDANCE OF LOW-THRUST INTERPLANETARY VEHICLES, (Ph.D. Thesis), Massachusetts Institute of Technology, Experimental Astronomy Laboratory, Cambridge, Massachusetts, June 1964, NASA CR-56188, N64-27301, Grant NsG-254-62.

The problem studied in this thesis is the guidance of interplanetary vehicles that are thrusting for a large portion of the transfer. The vehicle is represented by a seven component state vector consisting of the position, velocity, and mass of the spacecraft. The analysis is linearized by assuming that the actual state of the vehicle differs only a small amount from a known reference state. The reference trajectory is assumed to be a propellant-optimal path connecting the initial and final points.

167. Moore, F. B. and Brooks, M.,
SATURN ASCENDING PHASE GUIDANCE AND CONTROL TECHNIQUES, Astronautics and Aeronautics, Vol. 10, 1963, pp. 183-209.

Adaptive guidance mode system under development at Marshall Space Flight Center must be sufficiently broad to accommodate variety of vehicle configurations and missions. Guidance and control system consists of four-gimbal inertial platform system with necessary items for maximum flexibility and unlimited attitude freedom, computing system capable of meeting requirements for all foreseeable missions, and analog control system that orients and stabilizes vehicle.

168. Mueller, R. R. and Gunckel, T. L., II,
ANALYSIS OF GUIDANCE, NAVIGATION, AND CONTROL SYSTEM EQUIPMENTS FOR MARS MISSION, IEEE International Space Electronics Symposium, Record 6-9 October 1964, Paper 4-c, 9 pp.

Considerations which must be examined in developing suitable guidance, navigation, and control systems for advanced, unmanned missions to Mars. Mission involved is assumed to include both injection of vehicle into orbit about Mars and soft landing of one or more vehicles upon Martian surface.

169. Mueller, R. R. and Gunckel, T. L., II,
AN ANALYSIS OF GUIDANCE, NAVIGATION, AND CONTROL SYSTEM EQUIPMENTS FOR A MARS MISSION, International Space Electronics Symposium, Las Vegas, Nevada, 6-9 October 1964, Record; New York, Institute of Electrical and Electronics Engineers, Space Electronics and Telemetry Group, 1964, pp. 4-c-1 to 4-c-9, A65-11460.

Included is a discussion of guidance, navigation, and control-system equipment for an unmanned mission to Mars involving both a soft landing and orbiting about the planet. Mission objectives, flight-control systems, communications, data-processing computers, and terminal navigation sensors are analyzed in terms of the general requirements of the mission. A broad and deep analysis of the complete vehicle system and associated astrionics systems is suggested.

170. Muntz, W. E.,
MARK TWAIN BEACONRY FOR LUNAR ORBITING AND LANDING, WESCON Convention Records, Vol. 6, Part 5 (Aeronautical and Navigational Electronics, Military Electronics, Space Electronics, etc.) Paper 9.2, 1962, 6 pp.

Soft lunar landings require distance measurements to be made rapidly and with reasonable accuracy over large dynamic ranges of velocity and altitude. A technique is described whereby phase-locked oscillator beacon is launched from spacecraft to moon. Range of space vehicle is obtained by Doppler cycle-counting technique.

171. McAllister, D. F.,
GIMBALLESS INERTIAL NAVIGATION IN LUNAR OR PLANETARY GUIDANCE, Astronautical Sciences, Vol. 8, 1963, pp. 415-424.

The "strap-down" system resulting from eliminating platform gimbals and mounting the inertial sensors directly on the space vehicle is functionally similar to a gimballed system, the main difference being the replacement of the gimbals by a small computer providing the direction cosines relating the vehicle orientation to a set of inertially fixed axes. This method is particularly suited to the space environment which facilitates the use of electrostatic and superconducting gyros. Two basic applications, the single axis and free gyro systems are analyzed in detail, and it is concluded

that the latter is potentially more accurate. Also considered is the utilization of strap-down systems in space navigation t. provide position and orientation fixes and midcourse correction.

172. McLean, J. D., SURVEY OF MIDCOURSE GUIDANCE AND NAVIGATION TECHNIQUES FOR LUNAR AND INTERPLANETARY MISSIONS, National Aeronautics and Space Administration-University Conference on Science and Technology of Space Exploration Proceedings, Vol. 1, November 1962, pp. 347-352.

Included is a survey of techniques used or considered for use during midcourse portion of space missions; examples presented are for primary guidance system and emergency methods which might be used for manned lunar mission; consideration of manned interplanetary flights indicates midcourse guidance problem, similar to that of lunar mission; and it appears that guidance will be more difficult than for lunar mission, particularly with respect to emergency procedures.

173. National Aeronautics and Space Administration, A FIXED-BASE-SIMULATOR STUDY OF THE ABILITY OF A PILOT TO ESTABLISH CLOSE ORBITS AROUND THE MOON by M. J. Queijo and D. R. Riley, June 1961, NASA TN D-917 (Unclassified).

A study was made on a six-degree-of-freedom fixed-base simulator of the ability of a human pilot to modify hyperbolic ballistic trajectories of a space vehicle approaching the moon so as to establish a circular orbit 50 miles above the lunar surface. The pilot was given control of thrust along the vehicle's longitudinal axis and torques about all three body axes. The results showed that by using a hodograph presentation of rate of descent and circumferential velocity, an altimeter, and vehicle attitude and rate meters, the pilots could consistently establish final altitude and velocity combinations that result in orbits lying within an altitude range of 10 to 90 miles above the lunar surface with a fuel consumption from one to three percent of the initial vehicle mass more than that required by the two-impulse Hohmann maneuver.

174. National Aeronautics and Space Administration, A STUDY OF GUIDANCE SENSITIVITY FOR VARIOUS LOW-THRUST TRANSFERS FROM EARTH TO MARS by A. L. Friedlander, February 1962, NASA TN D-1183 (Unclassified).

An analysis of guidance sensitivity based on methods of linear perturbation theory and adjoint functions is presented. The fundamental guidance equation is derived and its interpretations are discussed. The characteristics of the sensitivity coefficients and functions for a typical low-thrust trajectory are described. The effects of initial velocity errors and thrust vector errors on the final position and velocity are presented for an extensive range of initial thrust-weight ratio, specific impulse, and transfer time.

175. National Aeronautics and Space Administration, AN ANALYSIS OF THE CORRIDOR AND GUIDANCE REQUIREMENTS FOR SUPERCIRCULAR ENTRY INTO PLANETARY ATMOSPHERES by D. R. Chapman, 1960, NASA TR R-55 (Unclassified).

The analysis of supercircular entry is developed around a new dimensionless parameter which combines certain conditions at the conic perigee altitude with certain characteristics of the vehicle. This parameter conveniently determines either deceleration-limited or heating-limited corridor widths for elliptic, parabolic, or hyperbolic approach trajectories. Illustrative calculations of corridor widths and the associated guidance problems are presented for Venus, Earth, Mars, Jupiter, and Titan. Generalized curves are presented for application to various entry conditions.

176. National Aeronautics and Space Administration, ANALYSIS OF ERRORS AND REQUIREMENTS OF OPTICAL GUIDANCE TECHNIQUE FOR APPROACHES TO ATMOSPHERIC ENTRY WITH INTERPLANETARY VEHICLES by D. P. Harry, III and A. L. Friedlander, 1961, NASA Tech Report R-102.

Included is an analysis and Monte Carlo statistical evaluation of potentially self contained guidance scheme based on clock and optical instrumentation considering entry velocities from 40,000 to 63,000 fps. Multiple-correction scheme is found capable of controlling approach using instruments of modest capability and requiring small corrective velocity increment.

177. National Aeronautics and Space Administration, STUDY OF STATISTICAL DATA-ADJUSTMENT AND LOGIC TECHNIQUES AS APPLIED TO INTERPLANETARY MID-COURSE GUIDANCE PROBLEM by A. L. Friedlander and D. P. Harry, III, NASA TR R-113, 1961 (Unclassified).

Included is a guidance theory to prescribe efficient trajectory control; statistical analysis and evaluation of effect of data-adjustment and decision techniques on efficiency of mid-course guidance maneuvers; optical navigation scheme is hypothesized and all random measurement errors are considered specified by Gaussian distributions; and basic guidance equations using linear perturbation methods.

178. National Aeronautics and Space Administration, Ames Research Center, Moffett Field, California, MIDCOURSE GUIDANCE FOR RETURN FROM THE MOON TO A GEOGRAPHICALLY FIXED LANDING SITE by J. D. McLean and L. S. Cicolani, March 1966, NASA TN D-3318, N66-17901, (Unclassified).

This report describes a midcourse guidance system for return from the moon to a safe landing at a specific geographical site. The design is based on linear perturbations about a reference trajectory. The vehicle's ability to maneuver within the atmosphere is used to reduce the midcourse corrective velocity requirements. The system is compared statistically on the basis of a digital computer simulation with one that uses fixed-time-of-arrival method of guidance. The trans-Earth injection errors, observation errors, velocity correction mechanization errors, and velocity correction measurement errors are specified by statistical distributions considered to be realistic in terms of present day capabilities. The fixed-landing-site guidance system requires substantially less corrective velocity than a fixed-time-of-arrival system, but it is more sensitive to errors in the final velocity correction than is the fixed-time-of-arrival system. This sensitivity can be effectively compensated for by proper scheduling of observations and velocity corrections or by the use of a rocket engine having different error characteristics for midcourse corrections.

179. National Aeronautics and Space Administration, Ames Research Center, Moffett Field, California,
MIDCOURSE NAVIGATION, GUIDANCE, AND CONTROL SIMULATION TECHNIQUES FOR A MANNED SPACECRAFT by D. W. Smith, February 1964, N66-12675, N66-12667 (Unclassified).

Midcourse navigation, guidance, and control of space vehicles are briefly discussed. The navigator tasks for making navigation measurements, performing computer operations, operating and aligning inertial measurement units, and performing midcourse velocity corrections are outlined. The simulation elements necessary to provide information to aid in solution of midcourse problems in these task areas were determined to be: an accurate outside visual scene containing stars, the moon, and Earth; a simulated vehicle cab; a computer to simulate the on-board computer; and computers to mechanize the long- and short-period equations of motion of the vehicle and the control-system equations which represent the inertial measurement unit. A direct optical planetarium is shown to provide an accurate outside visual scene for the least cost in the shortest time, and motion and system response requirements are developed for a simulator capable of simulating a wide range of vehicles and control systems.

180. National Aeronautics and Space Administration, Ames Research Center, Moffett Field, California,
RELATION BETWEEN LUNAR AND INTERPLANETARY MIDCOURSE GUIDANCE TECHNIQUES (U) by J. S. White, X64-12310 (In NASA, Washington, D. C., Guidance, Control, and Communication, July 1963, pp. 67-77, X64-12306) (Confidential).

Not abstracted.

181. National Aeronautics and Space Administration, Langley Research Center, Langley Station, Virginia,
GUIDANCE PROCEDURES FOR PLANETARY ATMOSPHERIC OPERATIONS (U) by J. A. White and J. W. Young, X64-12314, (In NASA, Washington, D. C., Guidance, Control, and Communication, July 1963, pp. 125-137, X64-12306) (Confidential).

Not abstracted.

182. National Aeronautics and Space Administration, Langley Research Center, Langley Station, Virginia,
INVESTIGATION OF METHOD OF PROGRAMMING CORRECTIONS ON GUIDANCE OF A SPACE VEHICLE APPROACHING THE EARTH (U) by J. A. White, X63-14571 (In NASA, Washington, D. C., Intercenter Technical Conference on Control, Guidance, and Navigation Research for Manned Lunar Missions, Ames Research Center, 24-25 July 1962, pp. 198-200, X63-14557) (Confidential).

Not abstracted.

183. National Aeronautics and Space Administration, Lewis Research Center, Cleveland, Ohio,
COMPARISON OF SEVERAL LUNAR DESCENT MANEUVERS (U) by V. Zimmerman, X63-14577 (In NASA, Washington, D. C., Intercenter Technical Conference on Control, Guidance, and Navigation Research for Manned Lunar Missions, Ames Research Center, 24-25 July 1962, pp. 268-292, X63-14557) (Confidential).

Not abstracted.

184. National Aeronautics and Space Administration, Manned Spacecraft Center, Houston, Texas,
A DESCRIPTION OF THE APOLLO SPACECRAFT GUIDANCE AND NAVIGATION SYSTEM (U) by D. W. Gilbert, X63-14558, (In NASA, Washington, D. C., Intercenter Technical Conference on Control, Guidance, and Navigation Research for Manned Lunar Missions, Ames Research Center, 24-25 July 1962, pp. 1-31, X63-14557) (Confidential).

Not abstracted.

185. National Aeronautics and Space Administration, Manned Spacecraft Center, Houston, Texas,
APPLICATION OF APOLLO GUIDANCE AND NAVIGATION TECHNIQUES TO MARS MISSIONS (U) by T. M. Carney, J. Funk, and P. J. Stull, July 1963, pp. 81-93, X64-12311 (In NASA, Washington, D. C., Guidance, Control, and Communication, X64-12306) (Confidential).

Not abstracted.

186. National Aeronautics and Space Administration, Manned Spacecraft Center, Houston, Texas,
LINEAR ACCELERATION GUIDANCE SCHEME FOR LANDING AND LAUNCH TRAJECTORIES IN A VACUUM by V. R. Bond, 1964, NASA TM X-51740, X64-35858 (Unclassified).

Not abstracted.

187. National Aeronautics and Space Administration, Manned Spacecraft Center, Houston, Texas,
LINEAR ACCELERATION GUIDANCE SCHEME FOR LANDING AND LAUNCH TRAJECTORIES IN A VACUUM by V. R. Bond, February 1965, NASA TN D-2684, N65-17119 (Unclassified).

Guidance equations are developed for guiding a spacecraft with finite continuous thrust from an initial position and velocity to a terminal position and velocity in a vacuum. The solution to this two-point boundary-value problem is obtained by assuming that the change in altitude and out-of-plane distance during the motion is small compared with the initial radius from the center of the attracting body to the spacecraft, and by prescribing linear acceleration for each of the three acceleration components. The resulting thrust, in general, is variable, but by introduction of a constraining relation, constant-thrust trajectories can be generated. Similarly, by introduction of another constraining relation, constant-pitch-angle trajectories may be generated. The guidance equations obtained may be used to guide a spacecraft to a landing on the moon, or to guide a spacecraft during launching from the moon. A comparison of these results with an optimum trajectory shows that the guidance equations yield a near-optimum trajectory for the case of a range-free, constant-thrust landing maneuver to a point near the lunar surface.

188. National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama,
AN ITERATIVE GUIDANCE SCHEME AND ITS APPLICATION TO LUNAR LANDING by H. J. Horn, D. T. Martin, and D. C. Chandler, July 1965, NASA TN D-2869 (Unclassified).

Not abstracted.

189. National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama,
ANALYSIS OF ERROR PROGRESSION IN TERMINAL GUIDANCE FOR LUNAR LANDING by P. J. Defries, July 1961, NASA TN D-605 (Unclassified).

A lunar descent scheme within periods of engine ON-OFF is investigated. Each period may have a different thrust level but it is constant for the length of the period. The engines are ignited by altitude and cut off by velocity signals. Five groups of errors are considered: ignition altitude (Δs), velocity change (Δu), thrust level (Δf), lunar gravitation (Δg), and initial approach velocity (Δw_0). Equations are derived that allow the computation of the influence of any given error occurring during any of the n periods on the final velocity at touchdown. It is concluded that it is principally advantageous to break up the descent into ON-OFF periods. Also it is inferred, as far as guidance is concerned, that the problem of descent rests with the very last period of braking. The upper periods can always be handled with constant thrust and rather crude instrumentation whereas the instrumentation for the last period depends upon the required softness of the landing which also determines whether or not variable thrust is necessary.

190. National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama,
APPLICATION OF AN ITERATIVE GUIDANCE MODE TO A LUNAR LANDING by H. J. Horn, November 1965, NASA TN D-2967 (Unclassified).

Not abstracted.

191. National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama,
ASTRIONICS RESEARCH AND DEVELOPMENT REPORT NO. 2, 1 May 1964, NASA TM X-53044, X64-36130 (Unclassified).

Not abstracted.

192. National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama,
IMPLEMENTATION REPORT NO. 1, STUDIES IN THE FIELDS OF SPACE FLIGHT AND GUIDANCE THEORY, 4 October 1963, MSFC MTP-AERO-63-70, N64-16521 (Unclassified).

This volume contains reports of NASA-sponsored studies in the area of space flight and guidance theory implementation.

193. National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama,
SEMI-ANNUAL PROGRESS REPORT, PART I - OART PROGRAM, SUPPORTING RESEARCH PROJECTS (U) by H. J. Coons, Jr., 22 June 1964, NASA TM X-53067 (Confidential).

This report presents the Office of Advanced Research and Technology Program of Supporting Research and is Part I of a three-part series which describes the George C. Marshall Space Flight Center's Supporting Research Programs in the reporting period 1 July 1963 through 1 January 1964.

194. National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama,
SEMI-ANNUAL PROGRESS REPORT, PART II - OMSF PROGRAM SUPPORTING RESEARCH PROJECTS (1 JANUARY 1964 TO 1 JULY 1964) (U), 1 November 1964, NASA TM X-53, 163 (Confidential).

Not abstracted.

195. National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama,
SPACE FLIGHT AND GUIDANCE THEORY - PROGRESS REPORT NO. 2, 15 June 1962, MSFC MTP-AERO-62-52, N63-18688 (Unclassified).

This paper contains progress reports of NASA-sponsored studies in the areas of space flight theory and guidance theory. The studies are carried on by several universities and industrial companies. This progress report covers the period from 1 December 1961 to 15 June 1962.

196. National Aeronautics and Space Administration, Moffett Field, California,
AMES RESEARCH CENTER SPACECRAFT DIGITAL COMPUTER SYSTEMS COMPONENTS RESEARCH (U) by J. V. Christensen and G. R. Marchant, 1962, X63-14597 (In NASA, Washington, D. C., Intercenter Technical Conference on Control, Guidance, and Navigation Research for Manned Lunar Missions, Ames Research Center, 24-25 July 1962) (Confidential).

Not abstracted.

197. National Aeronautics and Space Administration, Washington, D. C.,
GUIDANCE, CONTROL, AND COMMUNICATIONS (U), July 1963, X64-12306 (Presented at the Manned Planetary Mission Technological Conference, Lewis Research Center, Cleveland, Ohio, 21-23 May 1963, NASA TM X-50120) (Confidential).

Not abstracted.

198. National Aeronautics and Space Administration, Washington, D. C.,
INTERCENTER TECHNICAL CONFERENCE ON CONTROL, GUIDANCE, AND NAVIGATION RESEARCH FOR MANNED LUNAR MISSIONS (U), X63-14557 (Ames Research Center, 24-25 July 1962, A compilation of the papers presented Washington, NASA, 1962, 506 pp.) (Confidential).

Not abstracted.

199. National Specialists Meeting on Guidance of Aerospace Vehicles, Proceedings Published by Institute of Aeronautical Sciences, New York, New York, 1960, Papers presented at Boston, Massachusetts, 25-27 May 1960, 250 pp., "Guidance and Control of Point Return Vehicles" by J. H. Lowry, Jr. and C. D. Buehrle, pp. 28-33; "Horizon Sensors for Vertical Stabilization of Satellites and Space Vehicles" by M. H. Arck and M. M. Merlen, pp. 34-39; "Accurate Determination of Attitude by Optical Means for Application in Space Vehicles" by G. V. Pahlenfedoroff, pp. 40-46; "Application of Optical Techniques to Interplanetary Navigation" by W. J. Haywood, Jr., pp. 47-52; "Magnetic Support for Floated Inertial Instruments" by P. J. Gilinson, Jr., and W. G. Denard, and R. H. Frazier, pp. 56-83; "Limit-Cycle Efficiency of ON-OFF Reaction Control Systems" by G. W. Freeman, pp. 84-97; "Pilot Control of Space Vehicle Tumbling" by J. W. Useller and J. S. Algranti, pp. 109-113; "Design of Propulsion and Stabilization System for Man in Cosmonotic Environment" by J. B. Griffin, F. T. Gardner, and M. L. Barnett, pp. 135-144; "Design Principles for Control Computer for Space Guidance" by R. L. Alonso and J. H. Laning, Jr., pp. 157-166; "Trajectory Problems in Cislunar Space" by G. Shapiro, pp. 167-177; "Terminal Guidance for Lunar and Planetary Probes" by R. H. Grube, pp. 178-183; "Differential Correction Method of Interplanetary Navigation" by H. G. Safren, pp. 184-190; "Study of Adaptive Control System Using Digital Simulation"

by T. R. Benedict, H. R. Leland, W. C. Schultz, and M. G. Spooner, pp. 191-196; "Application of Adaptive Control Techniques to Aerospace Vehicles" by W. F. O'Neill and M. J. Abzug, pp. 197-208; and "Method of Graphical Trajectory Analysis" by A. S. Boksenbom, pp. 209-221.

Not abstracted.

200. Naval Research, Office of, San Francisco, California, RESEARCH RESERVE SPACE SCIENCE SEMINAR: SUMMARY OF PRESENTATIONS SPONSORED BY OFFICE OF NAVAL RESEARCH, 20 OCTOBER-NOVEMBER 1963, TREASURE ISLAND, SAN FRANCISCO. CALIFORNIA, November 1963, AD-429 096 (Unclassified).

CONTENTS

201. Naval Supersonic Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts, A FEASIBILITY STUDY AND CONCEPTUAL DESIGN FOR OPERATION UNMANNED LUNAR MISSIONS FOR 1964-1965, VOLUME II, 15 August 1961, NSL 62-55 (Unclassified).

This second volume of a study on an unmanned, lunar roving vehicle mission and an unmanned, lunar Earth return vehicle mission is devoted to the return vehicle mission.

The mission requirements are outlined and a systems description included. The return vehicle bus and return vehicle are discussed, giving system requirements, design analyses, and system designs for these vehicles.

202. Naval Supersonic Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts,
A FEASIBILITY STUDY AND CONCEPTUAL DESIGNS FOR OPERATIONAL UNMANNED LUNAR MISSIONS FOR 1964-1965, VOLUME III, 15 August 1961, NSL 62-55 (Unclassified).

This third volume of a study on an unmanned, lunar roving vehicle mission and an unmanned, lunar Earth return vehicle contains two composite block diagrams of the roving vehicle and bus.

203. Newman, R. A.,
TIME LAG CONSIDERATION IN OPERATOR CONTROL OF LUNAR VEHICLES FROM EARTH, American Rocket Society, Lunar Missions Meeting, Cleveland, Ohio, 17-19 July 1962, (Technology of Lunar Exploration, Progress in Astronautics and Aeronautics, Vol. 10) London, Academic Press, Inc., 1963, pp. 589-613, A63-23439.

Included is a discussion of the nature and effect of time lags in the control loop for a roving lunar vehicle controlled from the Earth. A display and control concept intended to compensate for the 1.25-second transmission delays in each direction of the loop, and for other time lags, is described. This concept uses predictive displays and is based on existing technical capability. It permits the operator to control the vehicle at the predicted point where the control instruction will take effect. The concept makes use of a computer to determine probable future vehicle position.

204. Noges, E.,
SIMULATION OF DIGITALLY CONTROLLED SYSTEMS, Proceedings of the National Electronics Conference (Chicago, 1961), Vol. 17, pp. 223-234.

In recent years increasingly stringent requirements have been placed upon the control and guidance systems of airborne and space vehicles. This has resulted in a more extensive use of digital controllers for guidance and control purposes. Because of the high degree of complexity the complete analysis

and synthesis of these systems by digital means is often impractical. If these tasks are to be performed on an operational analog computer, it is necessary to employ special techniques in the simulation of the digital controller. The simulation of multirate digitally controlled systems is discussed. Two methods of simulating the pulsed transfer functions are considered: (1) the direct method which consists of forming linear combinations of past and present values of the input and (2) the Sklansky method, in which the pulsed transfer function is obtained by the use of two sampler-hold circuits and continuous transfer functions. These methods are found to be comparable if ideal samplers are used. In physical systems, the limitations imposed by the equipment may make either one or the other method of simulation more desirable. An electronic digital controller simulator capable of simulating multirate digitally controlled systems which contain computation delay is described. The performance of this simulator is evaluated and found to be satisfactory for sampling rates between 2 and 0.002 sampling periods per second.

205. North American Aircraft,
PRELIMINARY DESIGN ANALYSIS OF A REMOTE CONTROLLED LUNAR ROVING VEHICLE by W. B. Sponsler, 13 October 1961, Norair N-269-61-9 (Unclassified).

This report outlines the general design considerations which influence the lunar roving vehicle configuration. It also describes the preliminary parametric mobility analysis and compares numerous vehicle configurations. In addition, pneumatic wheel, rigid wheel, and tracks are compared qualitatively. Trends, general recommendations, and proposed future studies are noted and several promising vehicle configurations are presented.

206. North American Aviation,
AEROSPACE PLANE PLANNING STUDY PROBATO/CR CONCEPT, VOLUME VII, PART 4 - SUPPORTING FIGURES AND DATA SUBSYSTEMS (U), 30 April 1964, NAA NA-64-300, Contract AF 33(657)-10989 (Secret).

Not abstracted.

207. North American Aviation, Autonetics, Downey, California,
FUTURE OF ONBOARD COMPUTERS FOR SPACE VEHICLES by G. H. Smith, June 1963, Autonetics Pub 550-A-66, AD-417 402 (Unclassified).

The initial applications of computers for space vehicles have been for performance of the functions of guidance and control. Digital computers capable of performing the functions of guidance, attitude control, steering, star tracking, display, permission checkout, and performance monitoring are in development. It can be expected that, in the near future, onboard computers will carry out the additional functions of in-flight checkout and other self test functions leading to in-flight maintenance.

208. North American Aviation, Inc., Space and Information Systems Division, Downey, California,
MANNED MARS AND/OR VENUS FLYBY VEHICLE SYSTEMS STUDY, VOLUME III - SPACECRAFT CONFIGURATIONS AND SUBSYSTEMS DESIGN, PART 1, FINAL REPORT by A. L. Jones and W. V. McRae. June 1965, NASA CR-65119 SID-65-761-3, X65-19079, Contract NAS9-3499 (Unclassified).

Not abstracted.

209. Northrop Space Laboratories, Space Systems Section, Huntsville, Alabama,
APOLLO EXTENSION SYSTEM PAYLOADS, SIMPLIFIED GUIDANCE AND NAVIGATION SYSTEM FOR LUNAR FLYING VEHICLE by A. V. Cohee, F. A. Clark, D. F. McAllister, and A. J. Taylor, May 1965, NASA CR-61057, N65-27674, Contract NAS8-20082 (Unclassified).

The manual control aspects of a lunar flying vehicle and the environmental factors which affect system selection are discussed. Factors, such as the harsh lighting of the lunar surface coupled with height and distance distortion due to the size of the moon are analyzed to determine if a manual system represents an improvement over a fully automatic system. A typical flight is simulated using an IBM computer program to determine the reserve fuel remaining at the target as a function of the mission profiles. It is concluded that for a 1100-foot altitude and a velocity of 900 ft/sec the mission profile will require 497 pounds for a 421-second flight. The requirement for maneuvering at the terminal end of the flight is discussed

and a simple radio frequency beacon is recommended due to limited time available at the terminus of the flight and to the large area of surveillance that the pilot must scan. Also, a system functional analysis is presented for each phase of the mission from liftoff, ascent, and vehicle alignment, to descent.

210. Noton, A. R. M., GUIDANCE OF SPACE VEHICLES BY RADIO MEASUREMENTS AND COMMAND, British Interplanetary Society - Journal, Vol. 18, No. 4, July-August 1961, pp. 132-138.

Included is a consideration of forms of post-injection guidance for lunar or interplanetary missions and radio command system which depends on ground radio tracking, computing, and command; ballistics theory and schemes of mechanization assuming use of small rocket (chemical propellant) in vehicle; computation of midcourse correction depends on orbit determination, based on radio tracking of vehicle by several sites at dispersed points on surface of Earth; and method of orbit determination and examples.

211. O'Hern, E. A., APPLICATION OF ADAPTIVE CONTROL TECHNIQUES TO AEROSPACE VEHICLES, Journal of Aerospace Sciences, Vol. 28, January 1961, pp. 66-67.

Not abstracted.

212. Ostgaard, M. A. and Butsch, L. M., ADAPTIVE AND SELF-ORGANIZING FLIGHT CONTROL SYSTEMS, Aerospace Engineering, Vol. 21, September 1962, pp. 80-81 and 115-116.

Not abstracted.

213. Packard, J. N., ELECTRO-OPTICAL IMAGE MATCHER FOR SPACE GUIDANCE APPLICATIONS, IEEE Transactions on Aerospace Navigation Electronics (USA), Vol. ANE-10, No. 3, September 1963, pp. 282-289.

Pattern recognition and the determination of relative attitude are capabilities of an electro-optical map matching device that utilizes two-dimensional correlation data processing techniques. This device is the basic element of a

Universal Space Tracker that provides pitch, yaw, and roll data with respect to the recognized field (either planetary surface, star field, or planetary rim) for space vehicle guidance applications. The correlation detector and data quantizer is a digital image camera of special design. A feasibility evaluation model of the map matcher has successfully correlated the constellation Gemini under a Maryland atmosphere. The implementation of optical correlation makes possible a universal tracking system with excellent performance characteristics. An advanced version of the tracker is expected to have a 20-arcsecond accuracy, a 5-degree instantaneous acquisition cone, a 20-degree field of view, a weight of five pounds, a one-fourth-cubic foot volume, and a three-watt power consumption.

214. Patterson, R.,
FLIGHT CONTROL FOR MANNED SPACECRAFT - GEMINI AND APOLLO - 1, IEEE International Space Electronics Symposium - Record 6-9 October 1964, Paper 7-b-1, 7 pp.

Included is a description of operation of attitude control and maneuvering electronics system (ACME) employed in Gemini spacecraft; system consists of five devices-attitude control electronics, orbit attitude and maneuver electronics, power inverter, and two redundant rate gyro packages.

215. Pennington, J. E. and Brissenden, R. F.,
VISUAL CAPABILITY IN RENDEZVOUS, Astronautics and Aerospace Engineering, Vol. 1, February 1963, pp. 96-99.

Not abstracted.

216. Peske, A. and Swanlund, G.,
CONTROL CONSIDERATIONS FOR A LUNAR SOFT LANDING, Aerospace Engineering, Vol. 20, February 1961, pp. 26-27.

Not abstracted.

217. Pfeiffer, C. G.,
DYNAMIC PROGRAMMING ANALYSIS OF MULTIPLE GUIDANCE CORRECTIONS OF A TRAJECTORY, AIAA Journal, Vol. 3, September 1965, pp. 1674-1681.

Not abstracted.

218. Pfeiffer, C. G.,
GUIDANCE OF UNMANNED LUNAR AND INTERPLANETARY SPACECRAFT, American Institute of Aeronautics and Astronautics, Astrodynamics Conference, New Haven, Connecticut, 19-21 August, 1963, Paper 63-399, 12 pp., Contract NAS7-100, A63-21716.

Included is a description of mathematical techniques for accomplishing Earth-based guidance of unmanned lunar and interplanetary spacecraft. The orbit determination and guidance correction aspects of the problem are developed from linear perturbation techniques well known in exterior ballistics problems. The treatment of correlated noise on the orbit determination data, a policy for determining when to perform impulsive guidance corrections to the orbit, guidance phases of a typical interplanetary mission, computation of the differential coefficients and the effect of second-order errors, a technique for optimal guidance of powered-flight trajectories, and the relationship of spacecraft and launch vehicle guidance analysis are considered.

219. Pfeiffer, C. G.,
GUIDANCE ANALYSIS, Lunar Missions and Exploration, New York, John Wiley and Sons, Inc., 1964, pp. 276-307, A65-13095.

Included is a discussion of the mathematical techniques used in designing the logical subsystem for a space vehicle guidance system. The mathematical treatment represents quite generally some of the most recent applications of modern control theory, and the analysis is slanted toward the guidance of unmanned spacecraft. The trajectory characteristics are described for the missions of lunar impact, flyby, soft-land, and orbit. An attempt is made to unify the discussion by showing that the fundamental notions of the linear perturbation theory and minimum variance estimation lead directly to the establishment of a guidance policy and orbit-determination procedure. This approach to control theory is said to have many applications and to have been widely discussed in the literature.

220. Pfeiffer, C. G.,
RUDIMENTARY LAUNCH GUIDANCE METHODS FOR DEEP SPACE MISSIONS, ARS Journal, Vol. 31, August 1961, pp. 1155-1158.

Not abstracted.

221. Pfeiffer, C. G.,
SIMPLE GUIDANCE FOR DEEP-SPACE BOOSTER VEHICLES, Astronautics, Vol. 6, No. 11, November 1961, pp. 30-31, 42 and 44.

Results of NASA Jet Propulsion Laboratory study are presented to demonstrate adequacy of simple guidance scheme; use of system requires additional midcourse propellant in amount less than three percent of spacecraft weight; injection guidance problem consists of determining instantaneous position and velocity of vehicle and computing steering and thrust-termination commands to achieve desired conditions; injection accuracy requirements; and error sources.

222. Pfeiffer, C. G.,
SOME THEORETICAL CONSIDERATIONS ARISING IN GUIDANCE ANALYSIS, Towards Deeper Space Penetration: Proceedings of an AAS Symposium Held as Part of 131st Meeting of the American Association for the Advancement of Science, Montreal, Canada, 29 December 1964, (AAS Science and Technology Series, Vol. 2, A65-22134) 1964, pp. 55-92, A65-22136.

Not abstracted.

223. Philco Corporation, Palo Alto, California,
INTERPLANETARY NAVIGATION AND GUIDANCE STUDY, VOLUME I: SUMMARY, 30 October 1965, WDL-TR2629, NASA CR-68558, N66-13130, National Aeronautics and Space Administration, Contract NAS8-11198 (Unclassified).

The scope of the study includes a statistical error analysis of the navigation and guidance systems for the midcourse and orbital phases of the Earth-Mars mission. A 532-day round-trip trajectory is used which is based on a 1975 launch opportunity and has high energies for both the outbound and return phases. In general, only random errors resulting from the navigation instruments and the guidance maneuvers are

considered. Four navigation system configurations are evaluated under the assumption that observation data are processed with a minimum variance Kalman filter to estimate the vehicle state. Sections 2, 3, and 4 of this report summarize the navigation and guidance theory, the computer simulation, and the onboard measurement techniques that have been used in the study. The principal results are discussed in Sections 5, 6, and 7 for the outbound midcourse, the return midcourse phase, and the Mars orbital phase, respectively.

224. Philco Corporation, Palo Alto, California, INTERPLANETARY NAVIGATION AND GUIDANCE STUDY, VOLUME III: ILLUSTRATIONS AND TABLES, 30 October 1965, WDL-TR-2629, NASA CR-68436, N66-13091, National Aeronautics and Space Administration, Contract NAS8-11198 (Unclassified).

Illustrations, graphs, and tables referenced in Volume II of the Interplanetary Navigation and Guidance Study are presented.

225. Philco Corporation, Palo Alto, California, NAVIGATION AND GUIDANCE ANALYSIS FOR A MARS MISSION, INTERIM STUDY REPORT by S. F. Schmidt and P. J. Rohde, 4 December 1964, WDL-TR2359, NASA CR-70635, N66-18317, National Aeronautics and Space Administration, Contract NAS8-11198 (Unclassified).

A modified error propagation program was used to simulate Earth based tracking in order to generate guidance and navigation data for a Mars mission. An analytical effort was made to define reasonable mathematical models of feasible onboard measurements. Calculations on guidance system configurations with parametric variations revealed tradeoffs between measurements and execution errors and the guidance accuracy attainable. A program study plan for data generation on tradeoffs between guidance system errors, navigation accuracy, and fuel requirements utilizing both Earth based tracking and computational facilities with reliance on telemetry to the spacecraft for command signals, was started.

226. Philco Corporation, Palo Alto, California,
OPERATIONAL AND FUNCTIONAL ANALYSIS FOR A SPACE FLIGHT GUIDANCE RESEARCH FACILITY by J. F. Brown, July 1964, WDL-TR-2291, NASA CR-58882, X64-16666, National Aeronautics and Space Administration, Contract NAS2-1891 (Unclassified).

Not abstracted.

227. Pickering, W. H.,
SOME THOUGHTS ON GUIDANCE SYSTEMS, Astronautics and Aeronautics, Vol. 2, No. 1, January 1964, pp. 70-75.

General guidance and control problems are surveyed with respect to guided missiles and space vehicles under various conditions, i.e., at launching, in free flight, rendezvous, etc.; man's role and participation; it is urged that interfaces between guidance and balance of spacecraft be examined and that guidance-systems thinking be directed to all aspects of entire system, including possible unconventional solutions or modifications of other elements of mission.

228. Porter, K. W., Jr. and Lange, E. H.,
TRENDS IN COMMAND SYSTEMS, IEEE National Aerospace Electronics Conference, Proceedings, 1963, pp. 84-89.

Included is a state of art and future trends in aerospace vehicle command systems; tabulation and discussion of system constraints imposed by range safety (command destruct function), real-time guidance and control, orbiting and interplanetary spacecraft, are given in terms of frequency, range, receiver type, information type, error importance, data rate, acquisition time, type of security, and major system considerations; and security here refers to such system characterizations as antijam, interference rejection, antispoof, tinker-proof, and private.

229. Radio Corporation of America. Burlington, Massachusetts,
VARIABLE POINT GUIDANCE STUDY, 15 July 1965, SSD-TDR-65-100, CR-588-145, AD-469929, X66-11400, Contract AF-04(695)-633 (Unclassified).

Not abstracted.

230. Rand Corporation,
A DISCUSSION OF A MIDCOURSE GUIDANCE TECHNIQUE FOR SPACE VEHICLES by F. T. Smith, 3 October 1960, Rand RM-2581 (Unclassified).

This memorandum discusses the application of some classical orbit-determination techniques to the synthesis of a midcourse guidance system for space vehicles. As an illustration, the case is considered where "range only" measurements of the vehicle's position are made from tracking stations on the Earth's surface. A reference orbit is defined by means of an ephemeris, and range residuals are formed. These residuals are used to correct the actual orbit, by a differential correction technique, to a two-body osculating orbit at a specific point of the reference orbit.

231. Reiss, M. H.,
NAVIGATION AND GUIDANCE TECHNIQUES FOR A MANNED LUNAR ROVING VEHICLE, American Institute of Aeronautics and Astronautics and Institute of Navigation, Astrodynamics Guidance and Control Conference, Los Angeles, California, 24-26 August 1964, Paper 64-656, 8 pp., A64-23828.

Discussion of an analysis of a typical early manned lunar roving vehicle known as the mobile laboratory (MOLAB) is included. The MOLAB concept is being considered as a means of extending and supporting landings of the Apollo Lunar Excursion Module. The analysis of a representative MOLAB mission is attempted to arrive at the navigation and guidance system functional requirements. Some special problem areas are discussed, involving: Earth-computed optimum paths, obstacle avoidance sensors and surface visibility, multifunction use of other equipment for navigation and guidance, piloting aids and displays, and Earth remote-control considerations. The various trade-off criteria on candidate techniques and the effects on the choice of a system concept are given. A system configuration that requires minimal equipment, but considerable input from the astronauts to perform the required navigation and guidance functions, is presented. The performance and growth of this configuration for selfcontained automatic operation are also discussed.

232. Renaudin, D.,
GUIDANCE OF ROCKETS AND SPACE VEHICLES (Guidage Des Engins Et Vehicules Spatiaux) Astronautique Et Recherche Spatiale, Paris, Dunod, 1964, pp. 204-213 (In French) (A64-26913).

Included is an examination of the structure of guidance systems for space vehicles. Two principal systems are distinguished: inertial guidance and radio-electric guidance. Both systems are said to present advantages and drawbacks, and their selection is said to depend on the specific mission to be accomplished. It is noted that other systems can be visualized which combine the advantages of both, namely, the mixed radio-inertial systems. It is concluded that the radio-electric guidance system is very powerful and accurate; it is less flexible, however, than the inertial system and calls for an important infrastructure on the ground.

233. Roberson, R. E.,
ASTRONAVIGATION - GUIDANCE AND CONTROL IN SPACE, Journal of Astronautical Sciences, Vol. 7, No. 4, Winter, 1960, pp. 87-95.

Included are celestial mechanics aspects of astrodynamics which are important in analyzing certain operational aspects of space vehicle applications some of which bear indirectly upon problems of guidance and control; problem of maneuver concept; low thrust maneuvers, and basic approaches used; processes involved in carrying system through set of kinematic states are shown schematically; and path control and attitude control.

234. Rodriguez, E.,
A METHOD OF DETERMINING STEERING PROGRAMS FOR LOW THRUST INTERPLANETARY VEHICLES, ARS Journal, ARS Reprint 645-58, 12 June 1958, 31 pp.

A simple method is presented for determining possible thrust-directioning and thrust magnitude programs to transfer a low-thrust vehicle between coplanar circular orbits about the sun. A two-body physical model and constant vehicle thrust to mass ratio are assumed. Through relations between energy per unit mass and angular momentum per unit mass, this method determines possible steering programs and avoids the costly, difficult, time-consuming trial and error process

of computing numerous trajectories to arrive at a possible steering program. Simple examples of steering programs with their machine computed trajectories illustrate the method.

235. Rogallo, V. L., and Savage, H. F.,
TWO-COMPONENT MICROBALANCE FOR MEASURING FORCES ON ION-BOMBARDED SURFACES, Review of Scientific Instruments, Vol. 34, No. 9, September 1963, pp. 988-991.

Null type balance for measuring forces due to ion bombardment on surface is used in experiments for determining forces that can modify trajectory and attitude of space vehicles, sensitivity of balance which employs principle of attracted disk electrometer, can be adjusted by changing location of center of gravity. Measurements of few μg of force in two perpendicular directions can be made simultaneously.

236. Rome Air Development Center, Space Defense Systems Laboratory,
A PRELIMINARY GUIDANCE ANALYSIS OF AN EARTH-MOON LIBRATION POINT VEHICLE by A. C. Diana, February 1963, RADC RAL-TM-63-2 (Unclassified).

To ensure mission success for space missions of the lunar and libration point variety, it will be necessary to provide some sort of enroute guidance. This report discusses guidance considerations and shows the effects of instrumentation errors on the accuracy in arriving at L_4. The main body of this report discusses the effect of burnout errors and midcourse trajectory errors on the miss distance at L_4.

237. Ross, S.,
A SYSTEMATIC APPROACH TO THE STUDY OF NONSTOP INTERPLANETARY ROUND TRIPS, American Astronautical Society, Annual Meeting, 9th, Los Angeles, California, 15-17 January 1963, Advances in the Astronautical Sciences, Vol. 13, North Hollywood, California, Western Periodicals Co., 1963, pp. 104-164, (A63-23391).

Included is an analysis of multilegged nonstop orbits passing both Mars and Venus during an uninterrupted trip. All likely mission areas in the 1970-1980 period, along with detailed studies of some interesting trips, are presented. A discussion of the advantages of applying vehicle propulsive

thrust during planetary passage is presented, together with a procedure for locating the "best" point of impulse application. Requirements and performance data for a special class of nonstop round trips, pertinent to the scheduling of solar probe missions, are discussed. These trips include close-approach flights past Venus which enable nominally low-energy paths to be bent closer to the sun.

238. Schechter, H. B. and McGann, J. V.,
GRAVITATIONAL FORCE FIELD IN VICINITY OF EARTH-MOON LIBRATION POINTS, AIAA Journal, Vol. 1, No. 4, April 1963, pp. 843-847.

Included is a two-dimensional gravitational acceleration field in the neighborhood of Earth-moon libration points investigated and the shape of contours of constant relative acceleration determined. Of particular interest for purposes of powered station-keeping is that, within a radius of 2500 mi around the libration points, thrust accelerations of not more than 10^{-3} fps will be adequate to maintain spaceships in a fixed position relative to Earth-moon frame of reference.

239. Schmidt, S. F.,
CONTROL AND GUIDANCE; THEORETICIAN FACES A MORE DIFFICULT TASK, Aerospace Engineering, Vol. 21, February 1962, p. 62.

Not abstracted.

240. Schmieder, D. H. and Winch, J. B.,
ADAPTIVE GUIDANCE, National Aeronautics and Space Administration, University Conference on Science and Technology of Space Exploration, Proceedings, Vol. 1, November 1962, pp. 339-346.

A concept of Path-Adaptive Guidance Mode is described and illustrated with simple examples: motivations for approach to guidance are shown as arising out of requirements of Saturn space vehicle and its wide variety of missions; and study and implementation of guidance mode involves special knowledge and research in disciplines of calculus of variations, celestial mechanics, and use of computers.

241. Schmieder, D. H., Winch, J. B., McLean, J. D., Houbolt, J. C., Bird, J. D., Queijo, M. J., Doolin, B. F., and Foster, J. V., CONTROL, GUIDANCE, AND NAVIGATION OF SPACECRAFT, Papers presented at Session K of the National Aeronautics and Space Administration, University Conference on the Science and Technology of Space Exploration, Chicago, 1-3 November 1962, N63-11501, NASA-SP-17 (N63-11507).

CONTENTS

1. Adaptive Guidance by S. H. Schmieder and J. B. Winch (NASA, Marshall Space Flight Center)
2. A Survey of Midcourse Guidance and Navigation Techniques for Lunar and Interplanetary Missions by J. D. McLean (NASA, Ames Research Center)
3. Guidance and Navigation Aspects of Space Rendezvous by J. C. Houbolt, J. D. Bird, and M. J. Queijo (NASA, Langley Research Center)
4. Space Vehicle Attitude Control by B. F. Doolin (NASA, Ames Research Center)
5. Guidance and Control Components Research by J. V. Foster (NASA, Ames Research Center)

242. Scull, J. R., GUIDANCE AND CONTROL OF THE MARINER PLANETARY SPACECRAFT, Presented at the IFAC Symposium on Automatic Control in the Peaceful Uses of Space, Norway, 21-24 June 1965, N66-18366, NASA CR-63753.

The unmanned exploration of the moon and nearby planets imposes very significant requirements on the guidance and control system of both the booster rocket and the spacecraft. The booster rocket must be launched into a narrow, moving corridor with great precision within a limited period of time. After separation, the spacecraft must be capable of providing corrections to the trajectory and controlling the orientation of solar panels, antennas, and scientific instruments. The guidance and control systems of the Mariner planetary spacecraft are described. Some of the techniques developed to provide redundant operation during the long interplanetary flight are discussed. Flight performance of the Mariner guidance and control systems is reported.

243. Schroeder, W. and Pittman, C. W.,
A GUIDANCE TECHNIQUE FOR INTERPLANETARY AND LUNAR VEHICLES, Planetary and Space Science, July 1961, pp. 64-69.

The problem of guiding an extraterrestrial vehicle during its launch phase by means of a closed-loop control system, using a large digital computer in real time, is discussed. Equations are derived from fundamental physics, from which the computer can determine the desired burnout conditions during flight. Steering equations are then derived, by means of which the vehicle will be guided to these burnout conditions in an efficient manner. Compared to the technique of guiding the vehicle to a trajectory determined before the flight, this method has the advantages that it is simple and flexible and it can accommodate a wider range of vehicle performance perturbations. The accuracy of the guidance technique is demonstrated by results from simulated flights to Venus.

244. Seacord, C. L.,
FLIGHT CONTROL, Space/Aeronautics, Vol. 42, No. 4, 1964-1965, pp. 66-69.

Not abstracted.

245. Seacord, D. L.,
FLIGHT CONTROL FOR MANNED SPACECRAFT, Space/Aeronautics, Vol. 40, No. 6, November 1963, pp. 72-80.

Included is a review of basic design parameters which largely determine functional and hardware design of flight control system of any manned spacecraft, namely, vehicle type, mission duration, mission objective, vehicle weight, and method of thermal equipment control; X-20 flight control system for delta-winged orbital glider; Apollo's command module's stabilization and control system; its control functions and elements; flight control for orbital stations; and future control systems.

246. Shulman, A.,
DISPLAY AND CONTROL IN MANNED SPACE VEHICLES, Astronautical Sciences Review, Vol. 11, 1962, pp. 271-298.

Included are results of study aimed at formulating display and control system suited to manual operation of manned space vehicles; system plan evolved features closed circuit TV for presenting either symbolic displays derived from vehicle sensor data or TV picture video from vehicle TV cameras; plan calls for translation of sensor data and operator control commands, carried out by digital control unit; control unit is comparable to special purpose digital computer facility.

247. Sjoberg, S. A.,
FLIGHT CONTROL AND MONITORING AND RECOVERY, Astronautics and Aerospace Engineering, Vol. 1, February 1963, pp. 70-74.

Not abstracted.

248. Skidmore, L. J. and Penzo, P. A.,
MONTE CARLO SIMULATION OF MIDCOURSE GUIDANCE FOR LUNAR FLIGHTS, AIAA Journal, Vol. 1, No. 4, April 1963, pp. 820-831.

Description and numerical results of Monte Carlo simulation to determine fuel requirements and final accuracy of midcourse phase is presented; example applies to two midcourse corrections to null errors in three terminal variables; proposed simulation for missions in which burnout errors are so large that nonlinear effects are important also is described; and aspects presented are basic system for fu and accuracy analysis, technique used for trajectory computations, determination of minimum velocity increment computation of midcourse correction errors, and estimated machine time/run.

249. Smith, G. L.,
MULTIVARIABLE LINEAR FILTER THEORY APPLIED TO SPACE VEHICLE GUIDANCE, Society for Industrial and Applied Mathematics, Journal, Vol. 2, No. 1, 1964, pp. 19-32.

System concept is developed for midcourse guidance of spacecraft that involves estimating vehicle's trajectory from noisy observations and then computing velocity corrections on

the basis of this estimate. The ability of such system to guide spacecraft accurately and efficiently is demonstrated by results of a digital computer simulation.

250. Smith, G. L.,
MULTIVARIABLE LINEAR FILTER THEORY APPLIED TO SPACE VEHICLE GUIDANCE, Society for Industrial and Applied Mathematics, Journal, Series A - Control, Vol. 2, No. 1, 1964, pp. 19-32, A65-14701.

Included is a treatment of the midcourse guidance problem by estimating the spacecraft's trajectory from noisy observations and then computing velocity corrections on the basis of the estimate. The estimation procedure is regarded as a filtering problem, and a guidance system concept is developed using multivariable linear filter theory. The ability of such a system to guide the spacecraft accurately and efficiently is demonstrated by the results of a digital computer simulation.

251. Southern California University, Electronics Sciences Laboratory, CONSOLIDATED SEMIANNUAL PROGRESS REPORT NO. 2, 30 September 1965, USCEE SAPR 2 (Unclassified).

Not abstracted.

252. Space Technology Laboratories, Inc.,
A TECHNIQUE FOR LUNAR LANDING SITE SELECTION BY EARTH-BASED CONTROL by W. A. Finley, January 1963, STL 9350.2-54 (Unclassified).

Not abstracted.

253. Space Technology Laboratories, Inc.,
SIMULATION OF TIME-DELAYED COMMAND SYSTEMS by H. F. Meissinger, 7 February 1963, STL 9350.6-19 (Unclassified).

Not abstracted.

254. Spence, W. N.,
ON THE ADEQUACY OF ICBM GUIDANCE CAPABILITY FOR A MARS LAUNCH, ARS Journal, 12 May 1960, ARS Reprint 1174-60.

A mathematical analysis of the errors involved in launching vehicles to Mars along a Hohmann orbit is made using Taylor's

Theorem. The effect of uncertainty in the astronomic unit on a Mars launch is evaluated and shown to be much smaller than the effect of expected launching errors. Expressions are worked out giving the position of entry into the gravity sphere of Mars versus error in the magnitude of the burnout velocity vector. The functions expressing the vehicle's motion as it enters Mars gravity sphere are given in closed form and are much simpler to use than an interactive digital computer process. It is shown that present-day ICBM guidance equipment is sufficiently accurate to place the vehicle within the near vicinity of Mars without the aid of midcourse guidance.

255. Springett, J. C.,
COMMAND TECHNIQUES FOR REMOTE CONTROL OF INTERPLANETARY SPACECRAFT. National Telemetering Conference, Proceedings, Washington, D. C., 23-25 May 1962, Paper 8-4, 13 pp.

Command system design and operation philosophy of Mariner series of spacecraft is discussed with emphasis on command modulation, detection, and decoding techniques.

256. Springett, J. C.,
TELEMETRY AND COMMAND TECHNIQUES FOR PLANETARY SPACECRAFT, ADVANCES IN COMMUNICATION SYSTEMS, New York and London, Academic Press, 1965, Vol. 1, pp. 77-128.

The fundamentals of communication links for spacecraft are examined. They fall into three main categories (tracking, telemetry, and command) and are subject to four major limitations; the maximum available transmitter power; the size and characteristics of the transmitting and receiving aerials; the free-space loss; and the noise temperature of the receiving system. These points are discussed and typical characteristics of transmitting and receiving systems for the NASA/JPL Deep Space Instrumentation Facility and for spacecraft of the Mariner and Voyager class are summarized. The telemetry and command system philosophy is discussed and in particular the necessity of having no errors in the command system is emphasized. A coherent phase-shift-keyed system is described and this leads to a discussion of the properties of a maximal-length linear shift-register code which is used in conjunction with phase-lock techniques to obtain both bit and word synchronization as well as a coherent demodulation reference. A two-

channel system which was used on the Mariner II spacecraft is described and also a single channel system which is a development of it. This will be used on future spacecraft in which the telemetering data rate will be between 5 and 5000 bits per second and command rates will be between 1 and 20 bits per second.

257. Staley, R. M.,
PERFORMANCE ANALYSIS OF AN OPTICAL-INERTIAL MIDCOURSE GUIDANCE SYSTEM ON A CIRCUMLUNAR MISSION, IEEE Transactions on Military Electronics, Vol. MIL-7, January 1963, pp. 70-79, A63-15064.

Included is a summary of the performance capabilities of a self-contained midcourse guidance system which uses a combination of optical and inertial equipment. The system is described, and its estimation errors, perturbations, and propulsive fuel requirements are presented for a typical circumlunar mission of 8.7 days. An appendix gives the details of the performance analysis.

258. Staley, R. M.,
PERFORMANCE ANALYSIS OF OPTICAL-INERTIAL MID-COURSE GUIDANCE SYSTEM ON CIRCUMLUNAR MISSION, IEEE Transactions on Military Electronics. Vol. MIL-7, No. 1, January 1963, pp. 70-79.

The self-contained midcourse guidance system described is a combination optical system which determines position and velocity perturbations from precomputer reference trajectory; inertial system controls velocity corrections which would be made to bring vehicle back to reference trajectory, and estimation errors, perturbations, and propulsive fuel requirements are given for typical circumlunar mission of 87 days' duration.

259. Stanford University, Stanford, California,
REMOTE LUNAR VEHICLE GUIDANCE STUDY STATUS REPORT, JULY 1964-JANUARY 1965 by R. E. Keller, 1965, NASA CR-62756, X65-15447, Grant NsG-111-61 (Unclassified).

Not abstracted.

260. Stanford University, Stanford, California,
REMOTE LUNAR VEHICLE GUIDANCE STUDY STATUS REPORT, JUNE 1963-JUNE 1964 by R. E. Keller and J. M. Leslie, 1964, NASA CR-56757, X64-35963, Grant NsG-111-61 (Unclassified).

Not abstracted.

261. Starkey, D. G.,
SPACE VEHICLE; MANNED VERSUS UNMANNED, Aerospace Engineering, Vol. 21, September 1962, pp. 88-89.

Not abstracted.

262. Stern, R. G.,
INTERPLANETARY MIDCOURSE GUIDANCE ANALYSIS, VOLUME II (Ph.D. Thesis), Massachusetts Institute of Technology, Cambridge, Massachusetts, 1964, 284 pp. (NASA CR-56895) N64-27871, Grant NsG-254-62.

Included in this volume are coordinate systems; celestial mechanics; graphical constructions; elliptical cylindrical coordinates; variant equations of motion; general matrix formulations; integration of the variant equations of motion for elliptical reference trajectories; determination of variant motion from first variations of orbital elements; variation in position, velocity, and acceleration; low-eccentricity reference trajectories; matrices for elliptical trajectories; fixed-time-of-arrival guidance; optimization of time-of-correction· singularities in the matrix solution for elliptical trajectories; and statistical theory.

263. Stiefel, E.,
MANY-BODY PROBLEMS AND INTERPLANETARY FLIGHT, Dynamics of Rockets and Satellites, Amsterdam, North-Holland Publishing Co., 1965, pp. 71-112, A65-27590.

Included is an examination of motion about a central body, transfer orbits, and three-body problem, and the transformation of Levi-Civita and parabolic orbits. Useful formulas for elliptic motion and orbit transfer are presented. A method is described which is adaptable, in flight-path problems, to solving the equations of motion.

264. Stuhlinger, E., ADAPTING WEAPONRY AND MATERIEL TO THE SPACE AGE, Army Information Digest, Army Inf Digest HT-1, 10 pp.

Not abstracted.

265. Sturms, F. M., Jr. and Cutting, E., TRAJECTORY ANALYSIS OF A 1970 MISSION TO MERCURY VIA A CLOSE ENCOUNTER WITH VENUS, American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 2nd, New York, New York, 25-27 January 1965, Paper 65-90, 20 pp., A65-14571.

Included is a preliminary analysis of the trajectory and guidance considerations for a close flyby of the planet Mercury by an unmanned spacecraft. The mission utilizes a trajectory having a close encounter with Venus enroute, and requires no powered flight after Earth injection except for guidance corrections. By using conic and integrated trajectories, a mission design is obtained which gives a launch period of 30 days extending from 28 July to 27 August 1970. The maximum launch energy for the mission allows significant payloads to be delivered by an Atlas-Centaur launch vehicle, and the mission can be accomplished with existing Earth-based radio guidance only, using three midcourse corrections at points about six days after injection, about six days prior to Venus encounter, and about eight days following Venus encounter. For each maneuver, the rms velocity requirements, orbit-determination error, and execution error are determined. The results indicate the feasibility of the mission.

266. Subotwicz, M., ASTRONAUTICS (SELECTED CHAPTERS) (Foreign title not available), Translated into English by Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, November 1963, FTD TT 61 123, AD-427 257, N50121 (Astronautyka, Warsaw, Panstwowe Wydawnictwo, Naukowe, pp. 20-36, 95-161, 192-203, 379-396, 460-463, 474-486, 1960)

This report includes space flight and existing possible forms of propellant, Newton's third law of motion and the law of the conservation of momentum, equations of rocket motion, nuclear fuels, magnetohydrodynamic propulsion (MHD), plasma engines, remote-control problems in rocketry, practical problems encountered in orbiting artificial satellites,

methods of tracking space rockets, and trajectories of non-powered flights to the moon.

267. Tapley, B. D. and Lewallen, J. M.,
SOLAR INFLUENCE OF SATELLITE MOTION NEAR STABLE EARTH-MOON LIBRATION POINTS, AIAA Journal, Vol. 2, No. 4, April 1964, pp. 728-732.

Motion of space vehicle in the vicinity of stable Earth-moon libration points is studied using a model which includes perturbing effects of gravitational attraction and radiation pressure of the sun. Differential equations of motion in a libration point centered coordinate system were integrated to determine vehicle behavior. Results indicate that, when effects of the sun are included, natural motions of vehicle placed initially at L_4 or L_5 will not remain near respective point; although vehicle moves on trajectory about the libration point for 700 days, influence of sun causes vehicle to move through wide departures from the libration point.

268. Tempelman, W.,
LINEARIZED IMPULSIVE GUIDANCE LAWS, AIAA Journal, Vol. 3, November 1965, pp. 2148-2149, A66-12801.

Included is the use of a generalized linear expression for constraints to obtain a general solution to the impulsive guidance problem. Two situations are considered: the case of four independent constraints and the case of minimizing a specified function while satisfying three independent constraints.

269. Thompson-Ramo-Wooldridge Systems, Redondo Beach, California,
ADVANCED CENTAUR EXPLICIT GUIDANCE EQUATION STUDY, FINAL REPORT by R. P. Davis, R. M. Staley, and J. P. Ivaska, 1 October 1965, TRW-4222-6043-K4-000, NASA CR-54609, N66-19485, Contract NAS3-3231 (Unclassified).

The feasibility of using a set of generalized guidance equations to direct a wide variety of future Centaur missions was investigated. Reasons are given why explicit guidance techniques are best suited to the purposes of the generalized guidance. A set of ground rules to define the missions which are considered to fall within the scope of a utility vehicle are presented. Theoretical developments of the recommended equations are given and performance results reported. A set

of computer requirements based on these equations is presented and their implications discussed. It was concluded that: (1) it is possible to design a set of equations which perform space tasks, and which can be accommodated by present day advanced flight computers; (2) the performance of these equations is comparable to, and can exceed the performance of, contemporary procedures; and (3) the current Centaur computer is not adequate to handle the requirement of an advanced set of equations, but might handle a version of equations which had a reduced mission accomplishment capability.

270. Thompson-Ramo-Wooldridge Corporation, Redondo Beach, California,
AN INTRODUCTION TO MIDCOURSE AND TERMINAL GUIDANCE by A. D. Wheelon, 10 June 1958, TRW GM-TM-0165-00252 (Unclassified).

Midcourse and terminal guidance is primarily concerned with correcting the ballistic trajectories of space vehicles. Since the sensitivity of free-flight trajectories to burnout errors increases with range, the advent of lunar and planetary flights lends considerable interest to this subject. Although midcourse corrections are frequently suggested as a catholicon for unfavorable ballistic error coefficients, very little fundamental scientific or systems engineering work seems to have been directed to the problem. A great deal of analysis must be performed to set the problems on a firm quantitative basis. This paper gives an introductory, analytic treatment of midcourse, and terminal guidance.

271. Thompson-Ramo-Wooldridge Corporation, Space Technology Laboratories, Redondo Beach, California,
MANNED MARS MISSIONS: A BIBLIOGRAPHY by L. R. Magnolia and S. A. Gogin, April 1965, AD-461 779 (Unclassified).

This bibliography consists of 348 annotated references dealing with manned Mars flyby and stopover missions, unmanned precursor missions, and Earth-based studies of Mars. The majority of the items are those published during the period 1955 to January 1965. The abstracts are primarily those written by the individual authors. If an author does not include an abstract with his paper, one is prepared from the text of the report using the author's words. If this is impractical, a brief summary statement or table of contents is provided.

272. Tschauner, J. and Hempel, P.,
A METHOD OF STEERING ROCKETS INTENDED TO MEET IN SPACE, Regelungstechnik (Germany), Vol. 12, No. 9, September 1964, pp. 389-397 (In German).

This article gives precise formula for the acceleration of a rocket which is to meet a satellite and offers a suggestion for the economical realization of this operation. Furthermore, it studies the problem of putting a rocket in orbit around the moon and shows the way to a practical solution.

273. Tung, F.,
LINEAR CONTROL THEORY APPLIED TO INTERPLANETARY GUIDANCE, IEEE Transactions on Automatic Control (USA), Vol. AC-9, No. 1, January 1964, pp. 82-89.

This article considers the problem of interplanetary guidance in the presence of random injection and measurement errors from the point of view of minimizing the expected value of the square of the control effort to meet a prescribed terminal accuracy. It is shown that the optimal control signal is a linear function of only those components of the predicted miss whose terminal covariance is specified. A one dimensional model which approximates the terminal phase of an interplanetary trip is considered in detail. Computer results are given showing the comparison of this solution with the minimum effort theory developed recently by Breakwell and Striebel on the requirement for the expected amount of velocity corrections. An analytical expression is given which shows that the present design is about 13 percent more costly insofar as the terminal portion of the expected velocity requirement is concerned.

274. United Aircraft Corporate Systems Center, Farmington, Connecticut,
STELLAR INERTIAL GUIDANCE STUDIES VOLUME II, SYSTEMS ENGINEERING, FINAL TECHNICAL DOCUMENTARY REPORT (U), March 1964, SCR-154-11, AD-357 499, Contract AF-33(657)-12625 (Secret).

This Stellar Inertial Guidance Studies Report is submitted in three volumes. Studies were conducted to determine requirements of an orbital application for the ballistic guidance plus control system previously developed. These requirements were then further expanded to packaging studies, systems analysis, systems engineering, and test planning. A

comparison of gimballed versus strapped-down inertial system techniques was also made to provide a documented report of the advantages and disadvantages of each.

275. University of Florida, Gainesville, Florida, WINTER INSTITUTE ON ADVANCED CONTROL, Proceedings Theme: Space Vehicle Guidance and Control, 1965.

Congresses on space vehicles include guidance systems, attitude control systems, command control systems, and adaptive control systems.

276. Vaeth, J. E. and Sarles, M. D., LUNAR LANDING GUIDANCE SYSTEM FOR SOFT-PRECISION LANDINGS, IEEE Transactions on Aerospace and Navigational Electronics, Vol. ANE-11, No. 4, December 1964, pp. 291-298.

Novel, minimum complexity guidance system for soft lunar landing is described; evaluation of predominant error sensitivities; selection of this system is influenced by its ability to handle wide range of initial conditions, sensor, propulsion, and control system errors with minimum fuel and accuracy penalty; and proof of performance is given in terms of analog and digital computer simulation results plus theoretical correlation.

277. Vitro Engineering Co., MISSILE AND SPACE PROJECT INFORMATION MANUAL, VOLUME IV-SPACECRAFT, January 1963, MSFC MTP-MS-IS-61-4, Contract NAS8-1552 (Unclassified).

The Missile and Space Project Information Manual is a compilation of descriptive data, firing summaries, and flight data on ballistic missiles and space vehicles. The data are presented in four volumes. Volume IV contains summaries for all known spacecraft launched by the United States and the USSR up to 23 April 1962. The term "spacecraft" as used here is limited to those payloads intended to achieve escape velocity from the Earth and to follow trajectories toward the moon, to the planets or into space between the worlds of the Solar System.

278. Wait, J. V.,
SIMULATION TECHNIQUES FOR AEROSPACE GUIDANCE AND CONTROL, Winter Institute on Advanced Control, Third, Space Vehicle Guidance and Control, Gainesville, Florida, 15-19 February 1965, Proceedings, A65-19051, Gainesville, Florida, University of Florida, Department of Electrical Engineering, 1965, 31 pp. (A65-19057).

Included is a brief comparison of the capabilities of analog and digital computing systems as they relate to aerospace simulation applications. Hardware and software considerations for large hybrid (analog-digital) simulation facilities are reviewed, and typical applications are described.

279. Weber, F. H.,
SATURN V INSTRUMENT UNIT, Society of Automotive Engineers, Paper SP-257, October 1964, pp. 97-102.

Basic, general information about Saturn V instrument unit is broken down into six major systems: structural, environmental control, guidance and control, measuring and telemetry, radio frequency, and electrical.

280. Welton, D. E., Bensky, S. M., and Hiland, J. R.,
TOWARD VARIABLE-THRUST LIQUID-ROCKET ENGINE, Astronautics and Aerospace Engineering, Vol. 1, No. 11, December 1963, pp. 77-81.

Throttling of rocket propulsion systems represents means for obtaining precise control of ballistic missile and space vehicle flight characteristics, and for enabling single rocket engine to accommodate propulsive requirements of different maneuvers. A review of principal mission areas in which throttling is required and a summary of major throttling techniques are included.

281. Woestemeyer, F. B.,
GUIDANCE REQUIREMENTS FOR AN UNMANNED PLANET LANDING, American Institute of Aeronautics and Astronautics, and Institute of Navigation, Astrodynamics Guidance and Control Conference, Los Angeles, California, 24-26 August 1964, Paper 64-645, 12 pp., A64-24343, Contract NASw-696.

Included is a discussion of the guidance problem linked with the separation of Landers from a vehicle on a flyby

trajectory, for landing at specified locations on Mars. The geometry of the problem is presented in detail, and the effect of errors is evaluated for landing sites in and out of the plane of the approach trajectory. The Schillings atmosphere is used as the basis of the computations, the differences that would result with an 11-millibar atmosphere being indicated. The downrange errors are found to be greater than the crossrange errors, both being sensitive to the range at separation.

282. Westinghouse Electric Corporation, Aerospace Division, Baltimore, Maryland,
STUDY OF BASIC REQUIREMENTS FOR A NAVIGATION, GUIDANCE, AND CONTROL SYSTEM FOR AN UNMANNED LUNAR LANDING VEHICLE, FINAL SUMMARY REPORT by E. J. Bowers, R. L. Taylor, E. H. Thompson, and J. W. Knight, December 1965, 329 pp., NASA CR-61118, N66-16570, Contract NAS8-11254.

This document is a final summary report for a study to establish basic sensor requirements for a spaceborne navigation, guidance, and control system capable of performing unmanned lunar landings from a point in the Earth-lunar midcourse trajectory to touchdown on the lunar surface. A determination of candidate systems and an exposition of possible tradeoffs is performed and, based on these results, a recommended system is derived. Sensor requirements, in the main, are found to be well within the state-of-the-art, the most severe requirement being that on measurement of vehicle-beacon line-of-sight rate during the main braking phase.

283. Wolff, M. F.,
SOLID-STATE NUCLEAR GYRO REPORTED FEASIBLE, Electronics, Vol. 35, 28 December 1962, pp. 48-51ff, A63-11117.

Included is a discussion of the significance of the recent development of an experimental directional gyro able to align protons, the orientation of which is then sensed. Magnetic resonance techniques are used. It is hoped that the nuclear gyro will eventually provide space-vehicle guidance without any moving parts.

284. Worth, R. N.,
A PILOT CONTROLLABLE PARACHUTE DESCENT SYSTEM FOR MANNED MARS LANDING VEHICLES, American Institute of Aeronautics and Astronautics, Annual Meeting, 2nd, San Francisco, California, 26-29 July 1965, Paper 65-385, 11 pp., A65-28965.

Included is a description of a landing system based upon the Northrop Cloverleaf steerable parachute attached to the vehicle with riser lines and two flap control lines. Separate propulsion systems are utilized, with a relatively small, horizontal-thrust, liquid rocket engine located halfway between the center of gravity and the parachute attachment points. In the flight mode, this engine augments the glide of the Cloverleaf parachute in producing horizontal flight. An integrated control system allows pilot control of glide angle through adjustment of flap deflection and/or of the horizontal thrust. In the landing mode a terminal-deceleration peripheral-configuration solid rocket engine is utilized to decelerate to final landing velocity. A landing leg system then absorbs the touchdown velocity, prevents toppling during skid-out, and provides ground clearance for subsequent launch operations.

285. Wright Air Development Center,
ARDC SYMPOSIUM ON GUIDANCE OF BALLISTIC MISSILES AND SPACE VEHICLES (U), July 1958, WADC TR 58-270, AD-155 599 (Secret).

This report gives an account of the presentations at the ARDC Symposium on Guidance of Ballistic Missiles and Space Vehicles held at Wright Air Development Center on 11-19 March 1958. Papers on ballistic missile vehicle guidance were included to delineate the guidance requirements for various types of missions. Information was presented on goals and guidance requirements for lunar and space missions. The papers present individual conclusions, which can be summarized as indicating that refinement of known techniques is required, and will generally suffice, to meet the guidance requirements of the various space missions.

286. Wright Air Development Center,
SOME FLIGHT CONTROL PROBLEMS OF A CIRCUMNAVIGATING LUNAR VEHICLE by G. Xenokes, March 1958, WADC TN 58-82, AD-151 111 (Unclassified).

Some problems of flight control for a vehicle required to pass around the moon and return to a braking ellipse in the Earth's atmosphere are investigated. It is shown that reliability will be an extreme problem for the mission. The need for velocity vector control for the mission is established and a method for accomplishing it is presented. In addition, velocity vector tolerances for successful recapture are investigated along with some brief considerations of landing at a preselected Earth site and of flight in nonterrestrial atmosphere.

287. Young, J. W., Foudriat, E. C., and White, J. A.,
GUIDANCE OF A SPACE VEHICLE TO A DESIRED POINT ON THE EARTH'S SURFACE, American Astronautical Society, Annual Meeting, 7th, Proceedings, Dallas, Texas, 16-18 January 1961, Advances in the Astronautical Sciences, Vol. VIII, New York, New York, Plenum Press, Inc., 1963, pp. 462-474 (A63-17653).

Included is an extension of previous studies into a complete concept for guidance of a vehicle from supercircular velocity to a predetermined area on the Earth's surface. The procedure consists of guidance to a particular perigee point, guidance from perigee to a close-in circular parking orbit, and reentry guidance either from perigee or from the parking orbit to the correct latitude and longitude on the Earth's surface. For the space vehicle to intercept the Earth's atmosphere at the correct altitude, it is necessary to apply corrective thrust during the final portion of midcourse guidance. Two methods for applying corrective thrusts are compared. One method consists of applying periodic corrective thrusts. In the other method, periodic corrective thrusts are applied depending upon the vehicle's position with respect to a dead band about the desired perigee altitude. Upon entering the Earth's atmosphere, the guidance system and requirements for attaining a close-in parking orbit are discussed. The final phase of the guidance program consists of reentry from the circular orbit to the desired latitude and longitude. Two methods are contrasted. The first method uses a fixed path, controls the vehicle to a reference trajectory in space terminating at the desired point. The second method provides a continuous

estimation of the terminal error and guides the vehicle so that the terminal error is zero.

288. Zee, C. H., ROCKET IN DRAG-FREE VERTICAL POWERED FLIGHT UNDER CONSTANT THRUST, Journal of Astronautical Sciences, Vol. 10, No. 4, Winter, 1963, pp. 119-121.

Second order nonlinear differential equation of motion in case of rocket in drag-free vertical powered flight under constant thrust is solved by series expansion containing nine terms: coefficients in series are in terms of given boundary conditions; truncation error of series is estimated, hence accuracy for practical problem based on analysis in paper could be well established; immediate applications are lunar landing and launching; and case of constant thrust acceleration is also solved.

289. Zhukov, A. N. and Lebedev, V. N., VARIATIONAL PROBLEM CONCERNING FLIGHT BETWEEN HELIOCENTRIC CIRCULAR ORBITS USING SOLAR SAILS (Foreign title not available) Translated into English from Russian by Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, 27 April 1964, N64-23857 (N64-23852).

This article considers the problem of finding optimum (in the sense of high-speed) guidance for flights from the orbit of the Earth to orbits of other planets in the solar system. Sail orientation with respect to solar rays is the guidance parameter. It is assumed that planet orbits are circular and coplanar. The resistance of the cosmic medium is considered to be small in comparison with solar pressure. This problem, with the aid of the maximum principle of L. S. Pontryagin, leads to a boundary-value problem for a system of eight differential equations solved on an electronic computer, the selection of missing initial conditions being made by the Newtonian method. The article concludes that, by using solar sails, it is possible to fly, without the expenditure of fuel, from the orbit of an artificial Earth satellite to the orbit of an artificial satellite of another planet in the solar system since the launching of a spaceship by means of a solar sail within the gravitational field of a planet also proves to be feasible.

290. Abate, J. E.,
THE NATURE OF ASTRO DOPPLER VELOCITY MEASUREMENT, IRE International Convention Record (USA), Vol. 8, Pt. 8, 1960, pp. 88-96.

This paper deals with astro Doppler velocity measurement for space vehicle navigation. The measurement yields the relative velocity of the vehicle with respect to a star, and requires the use of electro-optical systems capable of measuring a small incremental change in the wavelength of propagated stellar energy. Such systems provide velocity data whose character and limitations are a function of the star's spectral radiation as well as the system instrumentation. This paper discusses the astro velocity data, its derivation, character, and limitations; and the Doppler velocity systems, their capabilities, limitations, and possible instrumentation.

291. Abate, J. E.,
STAR TRACKING AND SCANNING SYSTEMS - THEIR PERFORMANCE AND PARAMETRIC DESIGN, 1961 IRE International Convention Record, Pt. 5, pp. 3-15, IEEE Transactions on Aerospace and Navigational Electronics, Vol. ANE-10, September 1963, pp. 171-181 (A64-10460).

Included is a consideration of optimum design and performance of startrackers and scanners whose ultimate application is the navigation and control of aerospace vehicles. Discussed are the basic startracking and scanning system and its functional elements, the input data, its inherent limitations, the optical systems, photomultipliers and the vidicon as possible radiation detectors, and the optimization of system performance through the manipulation of major design parameters.

292. Aeronautical Research Associates of Princeton, Inc.,
CONCEPTS OF NAVIGATION IN SPACE by J. C. Houbolt, April 1964, ARAP 58 (Unclassified).

Transfer trajectories and determination of rendezvous trajectories are discussed in this report.

293. Air Force Cambridge Research Center,
MAGNETIC DETERMINATION OF SPACE VEHICLE ATTITUDE (U) by J. F. McClay and P. F. Fougere, March 1959, AFCRC-TR-59-212, AD-305-904 (Secret).

Not abstracted.

294. Air Force Cambridge Research Laboratories,
CELESTIAL BACKGROUND RADIATION 1-A REVISED SCALE OF BOLOMETRIC CORRECTIONS by R. G. Walker, March 1964, AFCRL-64-169(I) (Unclassified).

A short review is given of the literature pertinent to the bolometric correction. A recommended scale of bolometric corrections is presented. The reduction of various photoelectrically determined magnitude and color systems to a common system and the further reduction of these measurements to absolute energy units is discussed in some detail.

295. Air Force Missile Development,
DESIGN OF STELLAR-INERTIAL GUIDANCE TEST FACILITY - FINAL REPORT by T. R. Dibble, July 1962, AFMDC TDR 62-8, Contract AF-29(600)-2984 (Unclassified).

This report presents the results of an industry survey, suggested test programs, and the methods and equipment for accomplishing the test programs. The survey investigated all celestial referenced navigation systems now in existence or anticipated during the next ten years. The results were utilized to establish the methods and equipment required to accomplish the necessary test programs.

296. Air Force Systems Command, Wright-Patterson Air Force Base, Ohio,
THE DEVELOPMENT OF CONTROL AND NAVIGATIONAL SYSTEMS by V. Seleznev (In its Aviation and Cosmonautics, 1964, pp. 20-30, X65-35843), X65-35846 (Unclassified).

Not abstracted.

297. Air Force Systems Command, Wright-Patterson Air Force Base, Ohio,
ON A TABLE OF TRAJECTORIES OF FLIGHT TO VENUS by Ye. P. Aksenov, Ye. A. Grebenikov, V. G. Demin, and Ye. N. Pirogov (In its Probl. of Motion of Artificial Celestial Bodies, 7 August 1964, pp. 233-238, N65-16526), N65-16545.

A special table of approximate initial data and elements of orbits of interplanetary flight is described that was constructed on the basis of consideration of motion of the spaceship in the Newtonian field of attraction of the sun. This table contains nearly 550 unperturbed trajectories of flight from Earth to Venus. In the calculations, it was assumed that Venus and Earth move in circular orbits in the plane of the ecliptic. Elements of the elliptic orbit (a, e, ω), heliocentric velocity of the spaceship at the initial moment, its direction, the geocentric velocity of the ship, its direction, and the relative location of Venus and Earth at the initial moment, are given in the table. This table may be used not only for tentative selection or orbits of flight and approximate initial data, but also for calculation of exact trajectories of flight. A series of trajectories of close passage near Venus were calculated with direct use of tabular initial data during integration of differential equations of perturbed motion. The results of one calculated trajectory are presented together with a description of the method used.

298. Air Force Systems Command, Wright-Patterson Air Force Base, Ohio,
PROJECT FORECAST USAF, NAVIGATION AND GUIDANCE REPORT, VOLUME I (U) by R. A. Duffy, January 1964, AFSC SCGF-64-12 (Secret R/D).

Not abstracted.

299. Air Force Systems Command, Wright-Patterson Air Force Base, Ohio,
PROJECT FORECAST USAF, NAVIGATION AND GUIDANCE REPORT, VOLUME II (U) by R. A. Duffy, January 1964, AFSC SCGF-64-12 (Secret R/D).

Not abstracted.

300. Air Research and Development Command, COMPUTATION METHODS AND TECHNIQUES FOR ASTRO-NAVIGATION APPLICATIONS (COM-MET-ASTRO), 18 April 1958, ARDC R&D Proj 1-4421 (Unclassified).

This project is for the development of digital computer methods and techniques for application to manned and unmanned vehicles. Increases in speed, performance, and utilization of the manned and unmanned weapons system have increased requirements for computation, speed, accuracy, reliability, temperature, size, weight, and cost. To meet future operational requirements, technical development programs are necessary in the digital computer techniques area. This project provides a source of digital techniques and components that are directed toward supporting advanced weapons systems.

301. American Astronautical Society, GIMBALLESS INERTIAL NAVIGATION IN LUNAR OR PLANETARY GUIDANCE by D. McAllister, January 1961, AAS-Preprint 61-38 (Unclassified).

Recently a new type of inertial navigation system, the gimballess or strapdown system, has come into prominence. In this system, the platform gimbals are eliminated, the inertial sensors being mounted directly to the vehicle. The advantage of this method in space vehicle guidance is that the platform gimbals are replaced by a more lightweight digital computer. In addition, the strapped-down mechanization is shown to be compatible with the ultra-high accuracy gyros of the near future, i.e., the electrostatically supported gyro and the superconducting or cryogenic gyro. In this paper, special emphasis is given to combination astroinertial strapdown systems in midcourse guidance and control.

302. Arck, M. H. and Wermser, E. M., INFRARED NAVIGATION SENSORS FOR SPACE VEHICLES, ARS Journal, 9 August 1961, ARS Reprint 1928-61.

This paper was presented at the Guidance, Control Navigation Conference on 7-9 August 1961, held at Stanford University. In the first phases of space exploration, we are concerned with navigation and observations in the parts of the solar system close to our own planet, the Earth. For navigational purposes on or near the surface of the Earth, it has long been customary to use the local vertical as a reference.

The commonly employed systems or methods for determining the local vertical are gravity sensing systems, inertial reference systems, and visual or infrared systems for observing the planet-space discontinuity. This paper describes the various types of sensor systems which have been developed to date; their applications, capabilities, and limitations.

303. Avrech, N.,
USE OF THE EARTH'S MAGNETIC FIELD FOR NAVIGATION AND ATTITUDE CONTROL, Institute of Radio Engineers Proceedings, Vol. 50, April 1962, p. 485.

Not abstracted.

304. Battin, R. H. and Laning, J. H., Jr.,
A NAVIGATION THEORY FOR ROUND-TRIP RECONNAISSANCE MISSIONS TO VENUS AND MARS, Planetary and Space Science (GB), Vol. 7, July 1961, pp. 40-56.

A self-contained navigation scheme is described and analyzed for the case of an unmanned spaceship launched from Earth and established in a free-fall solar orbit that passes within a few thousand miles of another planet and subsequently returns to Earth. A statistical study of the navigation errors and the micro-rocket fuel requirements is made, using a three-dimensional model of the solar system. Several different trajectories are subjected to a systematic study to determine the optimum times at which positional checks and velocity corrections should be made in order to minimize both the amount of fuel required and the errors in passing distance at the target planet and miss distance upon return to Earth.

305. Battin, R. H.,
A STATISTICAL OPTIMIZING NAVIGATION PROCEDURE FOR SPACE FLIGHT, ARS Journal, 15 October 1961, (ARS Reprint 2297-61).

In a typical self-contained space navigation system, celestial observation data are gathered and processed to produce estimated velocity corrections. The results of this paper provide a basis for determining the best celestial measurements and the proper times to implement velocity corrections. Fundamental to the navigation system is a procedure for processing celestial measurement data which permits incorporation of each individual measurement as it is made

to provide an improved steimate of position and velocity. To "optimize" the navigation, a statistical evaluation of a number of alternative courses of action is made.

306. Bazhinov, I. K.,
METHOD OF AUTONOMOUS GUIDANCE DURING FLIGHTS IN NEAR-PLANET ORBITS (Metod Avtonomnoy Navigatsii Pri Poletakh Po Okoloplanetnym Orbitam) Translated into English from Russian by National Aeronautics and Space Administration, Washington, D. C., NASA-TT-F-9542, May 1965, 11 pp., N65-33802 (Presented at the Second Annual Conference of the American Astronautical Society, Chicago, 4-7 May 1965).

A method for autonomous navigation of a spacecraft, under full control of the astronauts, is described, based on practical experience of the Voskhod-2 flight. Conventional navigation methods are used on board the craft, taking fixes on two heavenly bodies preselected by the ground station before blast-off.

307. Bazhinov, I. K.,
METHOD OF SELF-CONTAINED NAVIGATION DURING FLIGHTS IN ORBITS NEAR PLANETS (Foreign title not available) Translated into English from Russian by Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, FTD-MT-65-148, 1 June 1965, AD-619479, N66-10855.

A simple method is presented of self-contained solution by cosmonauts of navigational problems during flight in orbits near planets by means of carrying out of astronavigational observations and measurements of altitude of flight. Thus, astronauts have to conduct simple calculations with the use of special navigational tables. The presence on board of any kind of computers is not obligatory.

308. Bendix Corporation, Ann Arbor, Michigan,
LUNAR NAVIGATION QUARTERLY REPORT, 6 JUNE-6 SEPTEMBER 1964 by W. G. Green, T. F. King, R. B. Odden, and T. T. Trexler, 17 September 1964, NASA CR-59137, BSR-1016, X64-17425, Contract NAS8-11292 (Unclassified).

Not abstracted.

309. Bliss, E. and Fromer, M.,
DESIGN OF SOLID-STATE RADAR TRANSMITTER UNITS FOR THE LUNAR EXCURSION MODULE, IEEE Transactions on Parts Materials Packaging (USA), Vol. PMP-1, No. 1, June 1965, pp. S257-263 (Electronic Components Conference, Washington, 1965).

The design of all-solid-state radar transmitters for satisfactory performance in translunar space or on the lunar surface poses many problems, the solution of which provides beneficial fallout for other applications. This paper discusses the design considerations which were combined to produce a highly reliable and sophisticated package adapted to accomplish, for a lunar excursion mission profile, the functions of velocity sensor and altimeter for a moon landing system, and of radar transmitter and transponder in a rendezvous-for-return system. The discussion covers the integrated electro-mechanical design of the basic unit, with typical performance parameters. Finally, packaging advances and the solution of thermal problems are described.

310. Blumhagen, V. A.,
STELLAR INERTIAL NAVIGATION APPLIED TO CRUISE VEHICLES, IEEE Transaction on Aerospace Navigational Electronics (USA), Vol. ANE-10, No. 3, September 1963, pp. 235-246.

Basic inertial navigation systems used in cruise applications will, in general, experience position errors that continue to increase with time. A cruise vehicle is considered here to be one which may be expected to operate for periods of time between a few minutes to several months, and at velocities from near zero to Mach 3 near the surface of the Earth. Various methods of augmenting the basic inertial system may be applied to alter the effect of the error sources by using information derived from external references. Among these are reference velocity, reference position, and stellar information. These references may be used individually or in any combination. This paper deals primarily with the concepts of utilizing stellar information in an inertial navigation system with some consideration given to the aspects of supplementing the stellar inertial system with reference velocity information. The effect of utilizing the stellar information is to eliminate the gyro drift as a major source of error in the system. In fact, the application of proportional plus integral

control will maintain the gyro bias compensation in a "tuned-up" condition so that in the event the stellar control is lost due to cloud cover or malfunction, the effect of the gyro contribution to system error will be minimized. The stellar inertial system will still experience unbounded errors (errors that continue to increase with time) due to random inputs since the appropriate error model has undamped normal modes; however, the theoretical ensemble rms position error is now a function of the square root of time instead of a linear function of time and it is possible to reduce the significance of the errors for reasonable periods of operating time with suitable stellar monitor design. The system errors can be bounded with the utilization of reference velocity for damping the system.

311. Bock, C. D.,
A HIGH PRECISION STELLAR NAVIGATOR FOR INTERPLANETARY GUIDANCE, Planetary Space Science (GB), Vol. 7, July 1961, pp. 57-63.

This stellar navigator uses the star-studded celestial sphere as its calibrated angular scale. Since the star positions are known to 0.01 inch of arc, this new class of instruments promises a substantial improvement in the precision of a fix over conventional startrackers. The proposed instrument centers its axis on a suitable planet. It then measures the angular distance to a star nearby on the celestial sphere, establishing a line of position. A second planet, well off this line, gives a second line of position. The intersection of these lines is the fix in space.

312. Campbell, M. E.,
A CELESTIAL ORIENTATION SYSTEM BASED ON STAR PATTERN RECOGNITION, American Institute of Aeronautics and Astronautics, and Institute of Navigation, Astrodynamics Guidance and Control Conference, Los Angeles, California, 24-26 August 1964, Paper 64-652, 19 pp. (A64-23334).

Included is a description of a conceptual system for the rapid measurement of space vehicle attitude, based on star pattern recognition, achieved through the spiral scan of an image tube detector. The system consists of optics and image tube, a small computer (or added memory to an onboard computer), controls and displays, and associated electronics. During a single electronic scan of the pattern, the train of star-pulses from the image tube is compared with simultaneous

pulse trains representing star patterns stored in the computer. A statistical interpretation of the number of coincident pulses provides recognition, hence, identification of one or more pre-selected reference stars for use in the precise determination of vehicle attitude. The spiral scan provides freedom from the usual problem of pattern rotation about the line of sight, while the pulse-matching technique eliminates time-consuming computation. The features of the system are: (1) no realignment required after restart, (2) no mechanical search, (3) tolerance of relatively high vehicle body rates, and (4) extremely rapid star identification and vehicle attitude determination.

313. Carroll, J. E. and Lillestrand, R. L., SIMULATION OF INTERPLANETARY NAVIGATION, ARS Journal, Vol. 32, December 1962, pp. 1923-1924 (A63-11557).

Included is a brief discussion of the advantages of an Earth-based simulation of lunar or interplanetary navigation using actual celestial targets. With this method, the position of the observing instrument relative to the Earth or the position of the Earth relative to the sun can be compared with known positions based on past astronomical measurements. The positions of Mars and Venus were favorable for such a test late in 1962. At that time, it was possible to conduct a simulation of interplanetary travel over a period of ten weeks. A somewhat shorter period of seven weeks is available in late 1964. A period of two weeks during which favorable conditions prevail occurs in mid-1965.

314. Cohen, D. F., A HYBRID STARTRACKER, Annual East Coast Conference on Aerospace and Navigational Electronics, 11th, Baltimore, Maryland, 21-23 October 1964, Technical Papers, A65-14925 05-21, North Hollywood, Western Periodicals Co., 1964, pp. 3.4.1-1 to 3.4.1-6 (A65-14960).

Included is a description of a hybrid startracker developed for use as an attitude reference system for spacecraft. The tracker is essentially a telescope in a two-degree-of-freedom gimbal system. It is continuously torqued to null the angular error between the target star and the position of the telescope. Pickoffs to suit interface requirements, as well as accuracy, are used to read the position of the stellar head with respect to the fixed base. Input energy flux from the star in the bandwidth of the detector is also determined and is used both to

identify the target star in the search mode, and to vary the forward loop gain for bright stars and increasing gain for dim stars. This automatic gain control permits torquin loop dynamics to be relatively independent of target star intensity.

315. Control Data Corporation, Minneapolis, Minnesota, INVESTIGATION OF NAVIGATION IN CISLUNAR SPACE - TECHNICAL DOCUMENTARY REPORT, MARCH-SEPTEMBER 1962 by R. L. Lillestrand, J. E. Carroll, C. B. Grosch, D. C. Harrington, and E. A. Mazorol, Jr., 17 December 1962, ASD-TDR-62-960, AD-292274, X66-12557, Contract AF-33(657)-8215 (Unclassified).

This report considers the use of track-while-scan optical systems operating in the visible region of the electromagnetic spectrum for Earth satellite and cislunar navigation. The detector is a wide-angle camera which employs slits in its focal plane. Fiber optics are used to convey the radiant energy to a photomultiplier. By measuring the time of appearance of celestial targets and transmitting this data to a digital computer, the position of the vehicle can be determined. An accuracy of five seconds of arc is achievable. The detector can provide information for both dynamic and static navigational systems. The equations necessary to compute the position of the vehicle for various navigational techniques are given. An extensive analysis of errors when navigating in cislunar space is given. Particular emphasis is placed on the problem of measuring the limbs of the Earth and moon. An accuracy of approximately 10 km is achievable at midcourse. The applied research reported in this document has been made possible through the support and sponsorship extended by the Aeronautical Systems Division. It is published for technical information only, and does not necessarily represent recommendations or conclusions by the sponsoring agency.

316. Cornell Aeronautical Laboratory, Inc., Buffalo, New York, SECOND QUARTERLY STATUS REPORT, 15 AUGUST TO 15 NOVEMBER 1962 - NASA REG STUDY NO. 1, PROBLEM DEFINITION STUDY FOR SPACEBORNE TRACKING AND NAVIGATION SYSTEMS by R. Taylor, 1962, Contract NASR-121 (Unclassified).

Not abstracted.

317. Crooks, J. W., Jr.,
A SIMPLIFIED HIGH PRECISION 200 MILLION MILE TRACKING, GUIDANCE, AND COMMUNICATION SYSTEM, Planetary Space Science (GB), Vol. 7, July 1961, pp. 94-107.

This article describes techniques suitable for tracking and guiding missiles to Mars and Venus of beyond. In simplest form, a system can be constructed utilizing these techniques, which requires only two ground stations a few thousand miles apart, linked only by voice or teletype communications and a transponder in the spacecraft to provide precise three-dimensional tracking information. One dimension is determined by making use of Earth motion, another dimension by the difference of distance from the spacecraft and the ground stations, and the third by direct range measurement.

318. Dahlen, J. M. and Nevins, J. L.,
NAVIGATION FOR THE APOLLO PROGRAM, Navigation for Manned Space Flight, 1964, Space Navigation Conference, St. Petersburg, Florida, 30 April and 1 May 1964, A66-11314 Washington, Institute of Navigation, 1965, pp. 27-70, (A66-11316).

This article includes a description of the many distinct regimes involved from launch, through translunar, lunar orbit, landing and rendezvous, return to Earth orbit, and reentry. Navigation functions (position and velocity determination, and computing of future conditions for a required maneuver) are separated from the guidance functions of powered maneuvers required to accomplish the navigation program. The equipment required to accomplish the navigations functions is described, with particular treatment of considerations regarding crew safety, spacecraft capability to complete mission, and mission flexibility. Use of onboard techniques versus external tracking and communication techniques is discussed. Many figures and illustrations accompany the text to provide a summary of the logic and systems problems involved in planning for accomplishment of the Apollo mission from the standpoint of navigation.

319. Electronics Corporation of America, Cambridge, Massachusetts, AUTOMATIC CELESTIAL - NAVIGATION SYSTEM (U) by D. J. Lovell. 15 June 1955, ECA RDO-R-556-416-SA7, AD-76 262, Contract AF-33(616)2574 (Secret).

Not abstracted.

320. Elfers, W. A., LUNAR NAVIGATION AND GUIDANCE, (American Astronautical Society, Symposium on Manned Lunar Flight; American Association for the Advancement of Science, Annual Meeting, 128th, Proceedings, Denver, Colorado, 29 December 1961) Advances in the Astronautical Sciences, Vol. X - Manned Lunar Flight, North Hollywood, California, Western Periodicals Co., 1963, pp. 82-101, (A63-17896).

Included is a discussion of the Astro Electronic Gimballess Inertial System (AEGIS). A system of three single-axis gyros, together with three body-mounted accelerometers, provides the bare minimum of instrumentation necessary to derive attitude and space position. It is found that AEGIS can handle the midcourse navigational problem within the errors specified. An inertial platform is not required. If the system is carefully fitted to vehicle dynamic characteristics, it is capable of providing reentry guidance and control as well. The system is feasible with state-of-the-art components and presents decided advantages in terms of weight, size, and power economy.

321. Elfers, W. A., LUNAR NAVIGATION AND GUIDANCE, American Astronautical Society, Advances in Astronautical Sciences, Vol. 10, 1961, pp. 82-101.

Current conventional platform systems are not adequate for space travel and additional startrackers are required to improve directional accuracies for referencing vehicle attitude; Astro Electronic Gimballess Inertial System consisting of three gyros and digital differential analyzer is considered as possible solution; and the system is capable of handling midcourse navigational problem within errors specified.

322. Fagin, S. L.,
A UNIFIED APPROACH TO THE ERROR ANALYSIS OF AUGMENTED DYNAMICALLY EXACT INERTIAL NAVIGATION SYSTEMS, IEEE Transactions on Aerospace and Navigational Electronics (USA), Vol. ANE-11, No. 4, December 1964, pp. 234-238.

A model for pure inertial navigation systems is defined which describes a wide class of dynamically exact systems for terrestrial and space applications. Based on this model a standard error block diagram is described and it is shown how the conventional simplifying assumptions lead to the specific version used for slow moving terrestrial applications. To efficiently treat augmented inertial systems, a generalized approach to error analysis of estimation systems is introduced. This approach (IEEE International Convention, New York, 23-26 March 1964) is amplified as it pertains to augmented inertial systems. It is shown how the standard error propagation block diagram can be used to place the augmented inertial navigation system error analysis in the canonical form necessary for a generalized error analysis. Augmentations considered are position, velocity, and attitude fixes. Specific examples are given.

323. Farrell, E. J., et al,
AUTOMATIC CELESTIAL GUIDANCE, Electronics, Vol. 39, 21 March-4 April 1966, pp. 115-124 and 94-105.

Not abstracted.

324. Federal Scientific Corporation, New York, New York,
EXPERIMENTAL VERIFICATION OF STAR IDENTIFICATION BY OPTICAL RADIATION ANALYSIS, TECHNICAL DOCUMENTARY REPORT, JULY 1963-JULY 1964, February 1965, AL-TDR-64-251, AD-614238, N65-27173, Air Force Avionics Laboratory, Wright-Patterson Air Force Base, Ohio, Contract AF-33(657)-11467 (Unclassified).

The purpose of this investigation is to experimentally verify prior theoretical conclusions that it is feasible for stars to be recognized from their radiation for use in the guidance and navigation of space vehicles. The experiments were performed at a terrestrial location with equipment capable of high precision measurements. The results indicate that within the atmosphere measurement accuracies are limited primarily

by the atmosphere, but are still adequate for reliable stellar recognition. The precision of the measurements achieved are a factor of two better than for data generally published.

325. Filkins, L. D.,
LOCATES - A WAY-OUT APPROACH TO NEARBY POSITION FINDING, Navigation, Vol. 11, Winter 1964-1965, pp. 379-386, A65-33777, (Institute of Navigation, Supersonic Transportation Meeting, 16 June 1964, Paper).

Included is a discussion of the concept, hypothetical performance, and potential uses of a position-fixing system applicable to both surface ships and objects and to air and space vehicles. This system concept has been named LOCATES, for Location of Air Traffic Enroute by Satellite. Three spherical surfaces of position, each containing the vehicle whose position is unknown, are established. Two of these are formed by simultaneously measuring the range from each of two stationary satellites (with known position) to the vehicle in question. The third is formed by knowledge of the vehicle altitude and its general geographic location; these may be known beforehand, as with ships, or may be measured on the vehicle and transmitted to a central computing facility, as with aircraft. The intersection of these three surfaces uniquely establishes the required position, except for one easily resolved ambiguity.

326. Flink, J. H.,
STAR IDENTIFICATION BY OPTICAL RADIATION ANALYSIS, IEEE Transactions on Aerospace and Navigational Electronics, Vol. ANE-10, September 1963, pp. 212-221, A64-10464, Contract AF-33(657)-8184.

Recognition of stars by means of their optical radiation characteristics is considered for use in the guidance and navigation of aerospace vehicles. Accurate spectral data obtained from observations using three wide-bandwidth optical filters are given for the 71 brightest stars, and the spectral parameters of a bright star are compared with previous observations made to identify the unknown star. It is shown that there are three easily measurable independent parameters in the radiation from individual stars which permit unique recognition of the brightest stars from above the Earth's atmosphere.

327. Franklin, R. G. and Birx, D. L.,
A STUDY OF NATURAL ELECTROMAGNETIC PHENOMENA FOR SPACE NAVIGATION, IRE International Convention Record (USA), Vol. 8, Pt. 5, 1960, pp. 122-134.

Radiations from the sun, stars, and interstellar space in both the visible and radio-frequency portions of the spectrum and also cosmic rays were investigated. Emphasis was placed on the measurement of velocity in space utilizing the Doppler phenomenon equipment and techniques useful in deriving velocity information from Doppler shift measurements are described and figures for expected accuracy are derived. Other passive techniques having possible application to space navigation such as the measurement of total solar radiation and solar diameter are briefly discussed.

328. Gransler, J. S.,
MECHANIZATION OF SELF-CONTAINED NAVIGATION SYSTEM, National Space Electronics Symposium, PTGSET Record, Paper 5.3, October 1963, 15 pp.

Mechanization of system capable of performing all guidance and navigation necessary for multiphased space mission is discussed; objective is to configure system which, from time of booster lift-off until time of reentry vehicle return, requires no external references; primary emphasis is on inertial and aided-inertial (stellar and planet tracker) systems; and hardware requirements, typical mechanization, error analysis, and orbital ephemeris determination are considered.

329. General Precision, Inc.,
FIRST ANNUAL TECHNICAL REPORT ON STUDY OF AUTOMATIC POSITION FIXING, VOLUME I (U) by L. N. Zechiel, June 1960, GPL-A20-4, AD-321 700, Contract AF-33(616)-6063 (Secret).

This report covers the work completed during the 12-month period 1 September 1968 through 31 August 1959 on theoretical and experimental studies for the development of an automatic position-fixing capability for airborne and space vehicles, based on an image correlation technique. A simple image correlator and a program of laboratory experiments using it are described. A theoretical study program in support of the equipment development is presented, and the results

of the year of study on problems affecting the feasibility of automatic position-fixing equipment based on the area-image correlation technique are reported.

330. General Precision, Inc.,
FIRST ANNUAL TECHNICAL REPORT ON STUDY OF AUTOMATIC POSITION FIXING, VOLUME II (U) by L. N. Zechiel, July 1960, GPL-A20-4, AD-321 701, Contract AF-33(616)-6063 (Secret).

This report contains the technical appendices pertaining to the first annual report on THE STUDY OF AUTOMATIC POSITION FIXING.

331. General Precision, Inc.,
SECOND ANNUAL TECHNICAL REPORT STUDY OF AUTOMATIC POSITION FIXING (U) by L. N. Zechiel, November 1960, GPL-A20-8, Contract AF-33(616)-6063 (Secret).

This is the final report in a series on a study of automatic position fixing techniques. The purpose of this program was to investigate experimentally, the feasibility of obtaining position fixing information by correlation techniques utilizing simple equipment in the visible light and infrared regions of the electromagnetic spectrum. The work accomplished includes analysis, design, and experimentation with laboratory equipment developed for the program. Results of this program of study and experimentation are presented, together with the results of a weather data study and investigations into the processing of discrete data and microwave information.

332. General Precision, Inc.,
FIFTH QUARTERLY TECHNICAL NOTE ON STUDY OF AUTOMATIC POSITION FIXING (U) by K. Hicks, May 1960, GPL-A20-5, AD-317 492, Contract AF-33(616)-6063 (Secret).

This report covers work during the period 1 September 1959 through 30 November 1959 on theoretical and experimental studies for the development of an automatic position-fixing capability, based on an image correlation technique. A discussion of the correlation process and a mathematical development of the process are presented. Mechanical design of the automatic correlator is described.

333. General Precision, Inc.,
SIXTH QUARTERLY TECHNICAL NOTE ON STUDY OF AUTOMATIC POSITION FIXING (U) by K. Hicks and L. Zechiel, July 1960, GPL-A20-6, AD-318 037, Contract AF-33(616)-6063 (Secret).

This report covers the work during the period 1 December 1959 through 29 February 1960 on theoretical and experimental studies for the development of an automatic position-fixing capability for airborne and space vehicles, based on an image correlation technique. The design of the electronic components of the automatic correlator is presented, and further work on the processing of discrete information is described. The effect of noise on detection of microwave radiation is evaluated.

334. General Precision, Inc.,
SEVENTH QUARTERLY TECHNICAL NOTE ON STUDY OF AUTOMATIC POSITION FIXING (U) by K. Hicks and L. Zechiel, July 1960, GPL-A20-7, Contract AF-33(616)-6063 (Secret).

This report covers work during the period 1 March 1960 through 31 May 1960 on theoretical and experimental studies for the development of an automatic position-fixing capability for airborne and space vehicles, based on an image correlation technique. The optical, mechanical, and electronic modifications to the automatic correlator which have been accomplished during this quarter are presented. Experiments with an automatic chart recorder readout system for studying correlation functions are described, and that status of weather data acquisition is discussed.

335. Geophysics Corporation of America,
LUNAR PHOTOMETRY FOR NAVIGATION by R. J. Levy, February 1962, GCA TR-62-10-A, AD-273 310, Contract AF-33(616)-7413 (Unclassified).

Available information on aspects of the moon's photometric behavior is reviewed and discussed as it applies to anticipated navigational measurements. Other topics include the spectral energy distribution of moonlight, the size and shape of the moon, and the risk of error in determining direction of the moon's center from measurements on its irregular limb.

336. Geophysics Corporation of America,
PHASE CURVES AND ALBEDOS OF TERRESTRIAL PLANETS
by G. de Vaucouleurs, June 1961, GCA TR-61-26-A,
AD-261 165, Contract AF-33(616)-7413 (Unclassified).

This study was undertaken as part of an investigation of navigation within the solar system by optical means. The objective of the investigation is to evaluate the suitability of various physical phenomena as sources of navigational information and to estimate the accuracy of navigational information obtained by various techniques.

337. Grammatikos, A.,
GIMBALLESS INERTIAL SYSTEMS FOR SPACE NAVIGATION
(Ph.D. Thesis) 28 July 1965, NASA CR-71089, N66-19527,
Grant NGR-39-010-029.

Two types of gimballess inertial systems for space navigations are studied: determining the attitude of a spacecraft from linear accelerometer measurements only, and error damping in the inherently unstable mechanization of the navigation equations in the inertial reference frame. Vehicular attitude can be determined from linear accelerometer measurements by properly placing an adequate number of accelerometers inside the vehicle in an arrangement termed accelerometer scheme. Five schemes of 12, 9, 8, 7, and 6 accelerometers are proposed, studied, and compared. The six-accelerometer scheme is considered to be the best. Inertial acceleration projections of the vehicular center of mass along the vehicular coordinate axes can be obtained with all the proposed accelerometer schemes. Mechanization of navigation equations in the inertial frame is most suitable for space navigation and consists of a direction cosine computer and the navigation loop which includes the necessary integrators and a gravity computer for gravity compensation. An error analysis of this mechanization shows that the direction cosine computer errors are sinusoidal whereas the navigation loop errors have sinusoidal and diverging components. To improve system performance, three error damping methods are proposed, studied, and compared.

338. Green, W. G.,
LOGARITHMIC NAVIGATION FOR PRECISE GUIDANCE OF SPACE VEHICLES, IRE Transactions on Aerospace Navigational Electronics (USA), Vol. ANE-8, No. 2, June 1961, pp. 59-71.

The principles of logarithmic guidance are derived and their application to various space-flight guidance problems discussed. Logarithmic guidance is shown to be ideal during the terminus of control where considerations of minimum fuel, minimum heating, etc., can be subordinated to precise matching of vehicle kinematics to the desired trajectory. This precise trajectory control is achieved utilizing velocity and position measurements to govern the vehicle deceleration. Multidimensional effects are considered and it is shown that various "degrees of control" of velocity vector magnitude and angle, time of arrival, accelerations, geographical or inertial directions of approach, etc., can be achieved. The tolerance of logarithmic guidance to instrumentation errors and parameter variations are confirmed by error analyses of these guidance principles applied to the control of the velocity vector during the deceleration process.

339. Haake, H. B. and Welch, J. D.,
MECHANIZING SPACE NAVIGATION SYSTEM, IRE Fifth National Symposium on Space Electronics and Telemetry Transactions, 1960, 22 pp.

Included are various methods that can be used to mechanize self-contained space navigation system, using positional perturbation guidance equation to compute velocity corrections. Key components are those used to determine present position, control system to implement velocity corrections, and computer to interrelate their functional operations.

340. Haake, H. B. and Welch, J. D.,
SELF-CONTAINED INTERPLANETARY NAVIGATOR, IRE Transactions on Aerospace and Navigational Electronics, Vol. ANE-8, No. 1, March 1961, pp. 28-41.

Included is a study of various methods that can be used to mechanize self-contained space navigation system, using positional perturbation guidance equation to compute velocity corrections. Key components involved are those used to determine present position, control system to implement velocity corrections, and computer to interrelate their functional operations.

341. Hartwell, J. G., Jones, A. L., and Danby, J. M. A., PLANETARY APPROACH NAVIGATION, Navigation, Vol. 11, Summer 1964, pp. 125-144, A64-24709 (Institute of Navigation Meeting, St. Petersburg, Florida, 1 May 1964).

Included is an assessment of the accuracy of midcourse guidance operations by studying the approach navigation phase of planetary flight. The approach navigation phase is also used to provide the necessary information to determine the desirability of a trajectory correction prior to flyby or capture. A study of navigation system requirements for this phase of spaceflight is made and a navigation technique is employed which is believed to be consistent with the use of optical sensors and a large number of measurements. A numerical example, based on an approach to Mars, is used to make a quantitative determination of the effects of variations in the sensor accuracy and of the effects of two kinds of data-processing filters on the performance of the navigation system.

342. Haviland, R. P. and House, C. M., CELESTIAL NAVIGATION IN SPACE, American Astronautical Society-Advances in Astronautical Sciences, Vol. 13, 1963, pp. 201-212.

Principles of celestial navigation on earth are extended to develop space navigation system suitable for manual operation by human observer; system uses conventional sextant sights and tabular calculations; nonambiguous positional information can be obtained readily; method of improving accuracy of data by means of multiple sights and by refined instruments; and methods of using data to determine departures from desired path.

343. Henry, J. L., Jr., ATTITUDE REFERENCE PROPERTIES OF INERTIAL NAVIGATION SYSTEMS, IEEE Transactions of Military Electronics (USA), Vol. MIL-7, No. 1, January 1963, pp. 15-18.

Most attitude reference systems function quite well under laboratory conditions but suffer considerable degradation in operational environments. A discussion is given of the excellent attitude reference information inherent in inertial navigation systems. Some limitations in reference system accuracy as a function of the characteristics of the gyroscopes

used are given. The discussion centers primarily on attitude information from Earth-oriented inertial navigation systems and includes considerations of both level and azimuth attitude information. Degradation of azimuth information at higher latitude is also discussed.

344. Hohmann, R. E.,
SOME EXTRAORDINARY IMPLICATIONS OF KEPLER'S SOMNIUM, ARS Journal, 8 December 1960, 8 pp., (ARS Reprint 1541-60).

The presentation of this subject considers (1) the sources of Kepler's logical theory, (2) Kepler's logical theory as outlined in the Somnium, (3) Soviet Lunik III data presenting empirical support of Kepler's logical theory, and (4) an estimate of the present-day use by the Soviet of Kepler's techniques of logical theory.

345. Institute for Defense Analyses, Research and Engineering Support Division
NAVIGATIONAL TECHNIQUES FOR TACTICAL OPERATIONS IN UNDERDEVELOPED AREAS, May 1963, IDA/RESD HQ 63-1610 (Unclassified).

Not abstracted.

346. International Astronautical Congress,
AN INTERPLANETARY NAVIGATION SYSTEM by E. V. Stearns, August 1958, IAF Congress 9-0.201.

A prototype system for interplanetary navigation is described with reference to a specific journey which has been selected to be a powered flight from Earth to Venus. The basis for the selection of a navigation system is presented, and relations between the mission characteristics and system mechanization are shown to determine the system to be employed. A solar-planetary triangulation system is described in which thrust orientation is monitored by an accelerometer-computer system and course-to-go is determined from a steering command computer. The system configuration is described together with estimates of performance.

347. Johns Hopkins University, Applied Physics Laboratory, Baltimore, Maryland,
FOUR TRANSIT NAVIGATING SYSTEMS WHICH UTILIZE INTEGRATED DOPPLER INFORMATION by V. Schwab, 19 September 1961, JHU/APL BBD-1055 (Unclassified).

Four similar transit navigating systems in which integrated Doppler information is used are presented. The results of preliminary numerical and analytic analyses indicate that possibly one or more of the four systems might be used to obtain the navigator's position with high accuracy.

348. Johns Hopkins University, Applied Physics Laboratory, Baltimore, Maryland,
SPACE PROGRAM - QUARTERLY REPORT, OCTOBER-DECEMBER 1964, December 1964, JHU/APL U-SQR/64-4, Contract NOw 62-0604-c (Unclassified).

Not abstracted.

349. Johns Hopkins University, Applied Physics Laboratory, Baltimore, Maryland,
SPACE PROGRAMS - QUARTERLY REPORT, June 1965, JHU/APL U-SQR/65-2, Contract NOw 62-0604-c (Unclassified).

Not abstracted.

350. Johns Hopkins University, Applied Physics Laboratory, Baltimore, Maryland,
SPACE PROGRAMS - QUARTERLY REPORT, JULY-SEPTEMBER 1965, September 1965, JHU/APL U-SQR/65-3, Contract NOw 62-0604-c (Unclassified).

Not abstracted.

351. Johns Hopkins University, Applied Physics Laboratory, Baltimore, Maryland,
USE OF AN ARTIFICIAL EARTH SATELLITE TO DETERMINE AZIMUTH (U) by E. E. Westerfield, February 1964, JHU/APL BB 320, Contract NOw 62-0604-c (Confidential).

Not abstracted.

352. Kearfott Division General Precision, Inc., Little Falls, New Jersey,
DESIGN, FABRICATION, AND TEST OF A FEASIBILITY MODEL RELATIVE STAR-ANGLE COMPARATOR, FINAL REPORT by P. Gevas, J. Abate, and G. Gulbenkian, May 1963, ASD TDR63 586, AD-430 013, Contract AF-33(657)-7997 4200 (Unclassified).

A new and unique aerospace vehicle attitude system, designed around the star-pair angle comparator, is described. The system basically measures the direction to any three of the 50 brightest stars, computes the angles between them, and processes the information to provide a two-star identification and a highly accurate spatial attitude determination. System operation and performance, along with a detail description of the feasibility model subsystems and their components are discussed. It is shown that the optical-electrical subsystems provide an equivalent startracker accuracy within 10 arc seconds. The overall system accuracy, including scanner, gimballing, and electronics, exceeds contractual requirements by a factor of two and is 20 arc seconds, demonstrated overall system error excluding computation error.

353. Kerner, T.,
SUN TRACKER CONTROL SYSTEM, Space Programs Summary, Vol. IV, No. 37-33, 30 June 1965, pp. 52-53, (N65-32422) (N65-32410).

A sun tracker control system is discussed. This control system is being designed to keep a parabolic mirror pointed at the sun to within a 30-second error. The mirror drive has two degrees of freedom, one in azimuth and one in elevation. For these two axes, the two control systems that govern the motions are identical. A block diagram of the mirror control system is shown. The system has been breadboarded in the laboratory with some modifications. A diagram of the breadboard circuitry is also shown. The linear sensor is substituted by a potentiometer-generated voltage in the loop, and the gear train driving the mirror has been reduced to a typical one-stage gear train driving a potentiometer. This was done on the assumption that the inertia and the friction load of the mirror are negligible as seen by the motor and that only the first gear is significant. The system performed satisfactorily in the closed-loop configuration.

354. Kizner, W.,
A METHOD OF DESCRIBING MISS DISTANCES FOR LUNAR AND INTERPLANETARY TRAJECTORIES, Planetary and Space Sciences (GB), Vol. 7, July 1961, pp. 125-131.

Miss distances for lunar and interplanetary trajectories can be described by specifying two components of the impact parameter, which is treated as a vector. This is analogous to the use of range and azimuth (or cross-range) in specifying the impact point for terrestrial targets. The resulting coordinates are very nearly linear functions of the variables of the trajectory near the Earth, except in cases where the trajectory is of the minimum-energy type, such as a Hohmann orbit. Applications are given to the theory of guidance and to a method for searching automatically for a trajectory which hits or misses the target in a specified manner.

355. Massachusetts Institute of Technology, Cambridge, Massachusetts,
SIMPLIFIED SELECTION OF OPTICAL FIX DATA AND A SIMPLIFIED GUIDANCE TECHNIQUE by W. F. Holbrow, Jr., (M.S. Thesis) 22 May 1964, AD-602 264, N64-32068.

A selective strategy for optical measurements in interplanetary navigation is shown in which the geometry of the situation dictates the decision. Variable time of arrival guidance is explained, and correction velocities are computed using the perturbation method and a simplified method based on the line of sight to the destination. The perturbation method is used as the ideal case for finding an empirical relation based on the line of sight. The empirical method derived could be used to check the computer solution in an actual flight, since it may be easily calculated manually by an astronaut.

356. Massachusetts Institute of Technology, Electronic Systems Laboratory, Cambridge, Massachusetts,
A STUDY OF COORDINATE-CONVERSION ERRORS IN STRAPPED-DOWN NAVIGATION by F. B. Hills, August 1965, ESL-R-244, AD-474 118, X66-13629, Contract AF-33(657)-11311 (Unclassified).

Not abstracted.

357. Massachusetts Institute of Technology, Experimental Astronomy Laboratory, Cambridge, Massachusetts,
THE MISSION FOR A MANNED EXPEDITION TO MARS by W. M. Hollister (Ph.D. Thesis, Middlebury College) Report TE-4, NASA CR-5-1067, X63-15174, and Grant NsG-254-62 (Unclassified).

Not abstracted.

358. Massachusetts Institute of Technology, Instrumentation Laboratory, Cambridge, Massachusetts,
A COMPARISON OF FIXED AND VARIABLE TIME OF ARRIVAL NAVIGATION FOR INTERPLANETARY FLIGHT by R. H. Battin, May 1960, IL R-283, Contracts NASw-130, AF-04(647)-303 (Unclassified).

Two types of self-contained navigation schemes are contrasted for the case of an unmanned spacecraft launched from Earth and established in a free-fall solar orbit destined to contact either Venus or Mars. A statistical study of the navigation errors and velocity corrections is made for several different trajectories using a three-dimensional model of the Solar System. It is shown that if a certain degree of flexibility is permitted in the arrival time at the destination planet, both the position accuracy and total velocity correction required can be improved by as much as a factor of two.

359. Massachusetts Institute of Technology, Instrumentation Laboratory, Cambridge, Massachusetts,
AN AUTOMATIC STARTRACKING SYSTEM by P. E. Packman, August 1958, MIT IL T-193, Contract NOrd 17366 (Unclassified).

An automatic startracking system may be applied to telescopes used for astronomical studies and has further application as a navigation aid. The parameters of a Stellar-Inertial type of system are developed theoretically and tests are carried out on a model system to verify these parameters experimentally. A new type of telescope transducer is used in the instrumentation of the system. This device is tested experimentally and improvements are suggested.

360. Minneapolis-Honeywell Regulator Co., St. Petersburg, Florida, A STUDY FOR AN ACCURACY DETERMINATION PROGRAM FOR THE PSEUDO-DIURNAL TRANSIT TECHNIQUE OF SPACE NAVIGATION ("PDT STUDY") PHASE I, FINAL REPORT, 17 November 1963, MH-HAR-2858-FR, NASA-CR-56288, N64-22473, Contract NAS1-2558 (Unclassified).

The PDT technique provides a means for establishing vehicle lines-of-position from near bodies by angular measurements derived from planet and star transits across a pair of reference "great circle" markers that are optically swept across the celestial sphere by the rotation of the mechanism about a single, known axis in inertial space (the pseudodiurnal axis). Direct measurements of declinations are avoided. A high-precision electro-optical transit detector is capable of resolving 0.168 arc second. The difficulties associated with scale readings are eliminated by application of a digital, dynamic goniometer (dynagon) with a 12-inch diameter rotor to the PDT axis, about which all angles are read; this device has a basic resolution of $\pm 0.15^{+}$ arc second. The pseudo-diurnal motion at constant rate, originally postulated, has been replaced by the central rotor motion of the dynagon, whose rate need be constant only during resolution between adjacent 1/8192th (of a circle) markers.

361. Moody, A. B., SPACE NAVIGATION, <u>IRE Proceedings</u>, Vol. 50, No. 5, May 1962, pp. 672-678.

Navigation techniques, measurements in space, and position determination are discussed. No order of magnitude improvement in state of art is needed to produce first-generation fully automatic space navigation system, but considerable development work is required.

362. Morgenthaler, G. W.,
LEAST SQUARES DETERMINATION OF SPACE VEHICLE'S RELATIVE RANGE AND ORIENTATION FROM FILM DATA, Journal of Astronautical Sciences, Vol. 10, No. 1, Spring 1963, pp. 8-14.

A technique is suggested for determining relative vehicle range and orientation from test or operational film data. The method gives least squares fit to assessor's observational measurements and is flexible enough to account for blurring or obscuring of points on film. It is a natural technique to be coupled with electronic computers in mass production data handling systems. The method is of interest as means of improving rendezvous technique or inspection of space vehicles for intelligence and policing purposes.

363. Moskowitz, S. and Weinschel, P.,
INSTRUMENTATION FOR SPACE NAVIGATION, IEEE Transaction on Aerospace Navigational Electronics (USA), Vol. ANE-10, No. 3, September 1963, pp. 289-306.

If a practical system is to be realized within the predictable future, the design of instrumentation for space navigation is contingent upon the meaningful definition of the mission, proper choice of navigation or guidance concept, optimum integration of the human operator, and independence from technological breakthroughs. The mission must be considered and categorized in terms of the characteristics of the observables rather than by any other method of classification. The mission also dictates the choice between implicit or explicit navigation concepts. The capabilities and limitations of the astronaut must be considered in the design of all equipment requiring viewing and manual manipulation, especially for computing purposes. The resulting equipment configuration may be considered in terms of the "spectrum of navigation instrumentation," ranging from completely manual to fully automatic operation. Such a design philosophy leads to a maximum probability of mission success despite partial equipment malfunctions. This paper is based in part upon the unclassified aspects of a study on space position fixing under sponsorship of the Air Force Aeronautical Systems and in part upon other space navigation programmes at the Kollsman Instrument Corporation. The material presented here serves an an introduction to the general topic of instrumentation

for space navigation and does not include the detailed exploration of any facet thereof.

364. Moskowitz, S. and Weinschel, P.,
NAVIGATIONAL INSTRUMENTATION FOR SPACE FLIGHT, Advances in Space Science and Technology, Vol. 6, 1964, pp. 101-169.

Included is an analysis of instrumentation requirements for space navigation and description of basic flight missions (orbital, lunar, and planetary), mission phases, and observables in space navigation in terms of flight phase; it is possible to employ any one of a number of implicit or explicit navigation schemes for a given mission depending on onboard computational capacities, available observables, and operational requirements of mission; major missions and their navigational requirements; and equipment configurations which satisfy specific problems are described.

365. Mundo, C. J.,
INERTIAL COMPONENTS TO SUPPLEMENT ASTROFIXES IN SPACE GUIDANCE, Planetary and Space Science (GB), Vol. 7, July 1961, pp. 19-25.

The requirements for inertial sensors in space navigation systems are discussed. Classically, terrestrial navigation has been based upon direct sensing of position and coordinate orientation. However, in space navigation another set of variables (thrust acceleration components) must be added to the conventional terrestrial set of measurements. These new variables are needed because, (1) different from terrestrial flight, an increment of applied thrust does not merely affect the course of the vehicle at the time it is applied, but it alters the whole path to the target and thus, if erroneously applied, must be totally cancelled out, (2) the measurements of position are so coarse that a very large error in position must be accumulated before a correction can be instituted. Inertial elements serve to ascertain instantaneously that trajectory-correcting thrust is being applied in the correct direction and that the total impulse is correct. However, the inertial components have no capacity for sensing the errors which arise during ballistic flight due to uncertainties in astronomical units, uncertainties in gravity, and integration errors internal to the system. The position elements may be viewed as the low-frequency sensing elements which measure the accumulated

errors, while the inertial elements are viewed as the high-frequency sensor which measures instantaneous errors in the system.

366. Naqvi, A. M. and Levy, R. J., SOME ASTRONOMICAL AND GEOPHYSICAL CONSIDERATIONS FOR SPACE NAVIGATION, IEEE Transactions on Aerospace and Navigational Electronics, Vol. ANE-10, September 1963, pp. 154-170, A64-10459, Contract AF-33(616)-7413.

From an astronomical and geophysical point of view, the use of optical measurements made with self-contained equipment in a space vehicle to determine its position and/or velocity is considered . Discussed are the type of measurements made from Earth, their temporal variations, and their accuracy as applied to space navigation. Information regarding stellar positions, magnitudes, spectra, and frequency distribution is presented. Considered are planetary positional ephemerides, diameters, phase curves, albedos, and spectral characteristics, and the advantages of using asteroids instead of planets.

367. National Academy of Sciences/National Research Council, UNITED STATES SPACE SCIENCE PROGRAM REPORT TO COSPAR, June 1963, NAS/NRC SSP-June 1963 (Unclassified).

This is a condensed compilation of reports on U. S. space-science activities received from numerous individual organizations and scientists, covering the period from the time of the last report through 1962, and in some cases, into the first months of 1963.

368. National Academy of Sciences/National Research Council, UNITED STATES SPACE SCIENCE PROGRAM REPORT TO COSPAR, May 1964, NAS/NRC SSP-May 1964 (Unclassified).

This is a condensed compilation of reports on U. S. space-science activities received from numerous individual organizations and scientists, covering the period from the time of the last report through 1963, and in some cases, into the first months of 1964.

369. National Aeronautics and Space Administration, ANALYSIS OF AN OPTIMAL CELESTIAL-INERTIAL NAVIGATION CONCEPT FOR LOW-THRUST INTERPLANETARY VEHICLES by A. L. Friedlander, May 1966, NASA CR-457 (Unclassified).

Not abstracted.

370. National Aeronautics and Space Administration, CELESTIAL GEODESY by W. M. Kaula, March 1962, NASA TN D-1155 (Unclassified).

The geodetic use of rockets, artificial satellites, and the moon is reviewed. The discussion covers in turn dynamics, geometry, observational techniques, comparison with terrestrial geodesy, and geophysical implications.

371. National Aeronautics and Space Administration, CHALLENGE OF SPACE EXPLORATION, NASA HT-8 (Unclassified).

This is a technical introduction to space. The space exploration vehicle, celestial mechanics, the space environment, operations in space, and man in space are items discussed.

372. National Aeronautics and Space Administration, MAJOR ACTIVITIES IN THE NASA PROGRAMS OF THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, 31 March 1960, NASA SAR-3 (Unclassified).

Not abstracted.

373. National Aeronautics and Space Administration, PILOTED SIMULATOR TESTS OF A GUIDANCE SYSTEM WHICH CAN CONTINUOUSLY PREDICT LANDING POINT OF A LOW L/D VEHICLE DURING ATMOSPHERE REENTRY by R. C. Wingrove and R. E. Coate, March 1961, NASA TN D-787 (Unclassified).

The guidance system studied is based on the concept of fast continuous trajectory computation from conditions existing along the trajectory. A method of display compares desired touchdown points with the maximum range capability and heating or acceleration boundaries, so that a proper decision and choice of control inputs can be made. Results

are presented from piloted fixed simulator tests for typical reentries with lunar mission velocities and for recoveries from aborts.

374. National Aeronautics and Space Administration, Ames Research Center, Moffett Field, California,
AN EMERGENCY MIDCOURSE NAVIGATION PROCEDURE FOR A SPACE VEHICLE RETURNING FROM THE MOON by C. D. Havill, March 1963, NASA TN D-1765, N63-14028.

A manual emergency-navigation procedure for a vehicle returning from the moon is presented. The procedure involves photographing the Earth from various positions along the trajectory returning from the moon, and deducing from image measurements the required midcourse corrections. Preliminary tests of the accuracy with which required image measurements can be obtained, together with machine computations of the overall accuracy of the guidance procedure, indicate the accuracy could be within the corridor depth of a lifting entry vehicle.

375. National Aeronautics and Space Administration, Ames Research Center, Moffett Field, California,
INVESTIGATION OF A MANUAL SEXTANT-SIGHTING TASK IN THE AMES MIDCOURSE NAVIGATION AND GUIDANCE SIMULATOR by B. A. Lampkin and R. J. Randle, May 1965, NASA TN D-2844, N65-24378.

The Ames Midcourse Navigation and Guidance Simulator has been used for defining problem areas associated with sextant sightings in a space navigation scheme, and for determining the relative accuracy of sextant sightings taken with a handheld sextant and with a gimbaled sextant. Sightings of this type would be used for determining the trajectory of a translunar or an interplanetary vehicle. The data indicate that, while the sextants used in this investigation require refining, they could probably be incorporated into a space navigation system. While the gimbaled sextant was slightly favored over the handheld sextant, the handheld sextant provided nominally as accurate sighting data as did the gimbaled sextant. Within the limitations of this study there was little effect of vehicle rotational motion about a single axis on sighting repeatability.

376. National Aeronautics and Space Administration, Ames Research Center, Moffett Field, California,
MIDCOURSE NAVIGATION SCHEME (U) by G. L. Smith and L. A. McGee (In NASA, Washington, D.C. Intercenter Technological Conference on Control, Guidance, and Navigation Researsh for Manned Lunar Missions, Ames Research Center, 24-25 July 1962, pp. 201-216, X63-14557), X63-14572 (Confidential).

Not abstracted.

377. National Aeronautics and Space Administration, Ames Research Center, Moffett Field, California,
TV RESEARCH AND AUTOMATIC TRACKER RESEARCH RELATED TO SPACE VEHICLES (U) by J. V. Foster, (In NASA, Washington, D.C. Intercenter Technological Conference on Control, Guidance, and Navigation Research for Manned Lunar Missions, Ames Research Center, 24-25 July 1962, pp. 481-489, X63-14557), X63-14599 (Confidential).

Not abstracted.

378. National Aeronautics and Space Administration, Langley Research Center, Langley Station, Virginia,
A STUDY OF SOLAR-SYSTEM GEOMETRIC PARAMETERS FOR USE AS INTERPLANETARY NAVIGATION AIDS by W. T. Blackshear and K. G. Johnson, July 1965, NASA TN D-2890, N65-28738.

Recognizable geometrical changes in the position of celestial bodies which may be observed by a pilot on a typical mission to Mars have been examined. Equations are presented for determining apparent positions of the sun and planets on the celestial sphere, angular diameter of the bodies, angle between various pairs of the bodies, phases, and possible eclipses and/or occultations. Typical charts are presented which would be useful in planning interplanetary navigational procedures.

379. National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama,
SEMI-ANNUAL PROGRESS REPORT, PART II - OMSF PROGRAM, SUPPORTING RESEARCH PROJECTS (U) by H. J. Coons, Jr., 22 June 1964, NASA TM X-53068 (Unclassified).

Individual OMSF tasks are presented within the appropriate study areas. Both inhouse and out-of-house tasks convey in condensed form the purpose, status, accomplishments, problems, and future plans of each study with illustrations.

380. National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama,
SEMI-ANNUAL PROGRESS REPORT, PART II - OMSF PROGRAM SUPPORTING RESEARCH PROJECTS, 1 JULY 1964 - 1 JANUARY 1965 (U), April 1965, NASA TM X-53237 (Confidential).

Not abstracted.

381. Naval Ordnance Test Station,
INTERPLANETARY NAVIGATION USING CELESTIAL REFERENCES by H. A. Wilcox, F. Pierce, and R. C. Haugher, 1 October 1958, NOTS 2081 (Unclassified).

This publication discussed the long-range navigation of interplanetary space vehicles. The dependence of the navigation problem on the means of propulsion is considered, as are the prediction of trajectory, the escape problem, and the capture problem.

382. Naval Weapons Laboratory,
TRANSLATION OF RUSSIAN PAPERS ON THE ERRORS IN NUMERICAL INTEGRATION OF THE EQUATIONS OF CELESTIAL MECHANICS by V. F. Myachin and A. S. Sochilina, 17 August 1961, NWL-17 August 1961 (Unclassified).

Papers on the estimation of the error resulting from numerical integration of the equations of celestial mechanics and the accumulation of numerical integration errors in some problems of celestial mechanics are included.

383. Newcomb, J. S., Willey, R. D., and Harrington, D. C.,
A WIDE ANGLE CELESTIAL ATTITUDE REFERENCE, Dayton, Institute of Electrical and Electronics Engineers, Dayton, Section, 1965, pp. 422-427, A65-29279, (National Aerospace Electronics Conference, 17th, Dayton, Ohio, 10-12 May 1965, Proceedings, A65-29228).

Included is a description of a scanning celestial attitude-reference device employing a fixed wide-angle optical system and rotating radial slit structure. Light from the star images in the slit is transmitted through fiber optics to the condensing lens system and then to a photomultiplier. An optical-angle encoder attached to the rotating slit is used to measure the position of the slit. The information obtained, which is converted into electrical pulses, is of three kinds: (1) the relative brightness of the star, (2) the azimuth angle of the slit at which

light from the star entered the slit, and (3) the azimuth angle at which the star image left the slit. This information is entered into a digital computer through appropriate interface logic. In the computer, the pattern of stars obtained after an appropriate number of scans is compared with a master star table, thus determining the orientation of the vehicle housing the reference device.

384. Nicklas, J. C.,
ANALYSIS, DESIGN, AND TESTING OF A POISTION SERVO UTILIZING A STEPPER MOTOR, ASME, Transactions, Series D, Journal of Basic Engineering, Vol. 85, June 1963, pp. 211-215, A63-22311, Contract NASw-6 (American Society of Mechanical Engineers, Joint Automatic Control Conference, New York, New York, 27-29 June 1962, Paper 62 - JACC-12).

Included is a description of a control system for a planetary horizontal platform (PHP) carried aboard a spacecraft. The platform will have two degrees of freedom, and on it will be mounted instruments for obtaining planetary data, able to move in relation to the spacecraft. The requirements for the PHP are that it be capable of acquiring the target planet within 10 minutes after the command for acquisition, that it be pointed toward the local vertical of the planet with an accuracy of ±0.5 degree, and that it be capable of tracking the planet at a maximum apparent planet angular velocity of three degrees per minute. A configuration for such a PHP is proposed, and a system model is determined. The stability of the system is analyzed theoretically and compared with the results of an experimental investigation of the model.

385. Northrop Aircraft, Inc.,
NOTES ON CELESTIAL NAVIGATION (U) by G. Gamow, 24 July 1948, NAI GM-525(0) (Confidential).

Not abstracted.

386. Northrop Corporation, Nortronics Division, Hawthorne, California,
OPTICAL LUNAR TRACKING TECHNIQUES PROGRAM INTERIM ENGINEERING REPORT NO. 3, 1 NOVEMBER 1961-31 JANUARY 1962 (U) by K. N. Satyendra, 1962, Contract AF-33(616)-8242, NORT-62-23, X63-11738 (Unclassified).

Not abstracted.

387. Northrop Space Laboratories, Hawthorne, California, SPACE OPTICS, A REVIEW OF FOREIGN TECHNOLOGY DURING 1963-1964, FINAL REPORT by R. S. Estey, June 1964, NSL-64-167, AD-458 556, McGraw-Hill, Inc., New York, Under Contract AF-33(657)-12199 (Unclassified).

This report presents an appraisal of the scientific and technological accomplishments of the Soviet Bloc nations for the purpose of evaluating the progression rate and to note significant scientific breakthroughs and advancements. Discussions cover the following subject headings: spacecraft instrumentation and components; space flight; trajectories and operations; guidance and control; space research; discussion of Polyot I: space navigation; satellite attitude control analysis of a technique; solar research; and a bibliography.

388. Novak, D. P., VISUAL RENDEZVOUS ALONG A FIXED LINE BY NULLING THE APPARENT DRIFT OF THE STAR BACKGROUND, Advances in the Astronautical Sciences, Vol. 16, Pt. 1, Space Rendezvous, Rescue, and Recovery, North Hollywood, California, Western Periodicals Co., 1963, pp. 199-215, A63-24754 (U.S. Air Force and American Astronautical Society, Space Rendezvous Rescue, and Recovery, Symposium, Edwards Air Force Base, California, 10-12 September 1963).

Included is an investigation of the short-range visual rendezvous technique, (the fixed line-of-sight method), which could be used by an astronaut who has neither radar or other complex electronic equipment available for navigation. The technique presupposes the astronaut's ability to navigate by nulling the apparent drift of a target in the star background to maintain a rendezvous trajectory on a fixed or nonrotating line in space. The method is analyzed by determining the relative motion of the astronaut with respect to the target, the rate of closure, and the total impulse expended per unit mass. The fixed line-of-sight methods maneuver is compared with two other possible short range transfer trajectories - the two-impulse and the rotating line-of-sight methods. It is found that for near-Earth orbits it is desirable to initiate the fixed line-of-sight maneuver from directly behind, rather than directly ahead of the target.

389. Ohlberg, E.,
METHODS OF STRAPPED-DOWN NAVIGATION, IEEE International Convention Record (USA), Vol. 11, Pt. 5, 1963, pp. 126-135.

Two basic strap-down platform systems of equations and the necessary digital computer characteristics for a navigation system utilizing each system of equations are derived. Also described are the necessary inertial component tolerances to implement these systems. The conclusions reached from this study are that strap-down navigation can be effected by any general purpose computer or general purpose-digital differential analyzer computer combination capable of implementing inertial platform navigation. For both systems of equations, the strap-down navigation can be separated into two computer tasks.

390. Oliver, E. F.,
INTERPLANETARY NAVIGATION, Navigation, Vol. 10, Winter 1963-1964, pp. 373-378, A64-14802.

Included is a discussion of some of the problems associated with interplanetary navigation in view of the future space flights to other planets. The major differences between terrestrial and interplanetary navigation, such as the introduction of the three-dimensional aspect, characteristic of the destination, and the angular field presented to the navigator, are discussed. Several plotting systems which will probably be used for the space fix are briefly described, including the heliocentric ecliptic coordinate system and the celestial equatorial coordinate system. It is indicated that electronic, inertial, and optical instrumentation, or any combination of the three, will consitute the navigational equipment. Finally, a hypothetical mission to make a heliocentric transfer to the orbit of the planet Mars and then replenish an observation station on the Martian satellite Probos is described.

391. Philco Corporation, Palo Alto, California,
THE APPLICATION OF STATE SPACE METHODS TO NAVIGATION PROBLEMS - TECHNICAL REPORT NO. 4 by S. F. Schmidt, July 1964, Philco/WDL TR 4 (Unclassified).

Not abstracted.

392. Philco Corporation, Palo Alto, California,
INTERPLANETARY NAVIGATION AND GUIDANCE STUDY, VOLUME III, 30 October 1965, WDL TR 2629, NASA CR-68436, N66-13091, Contract NAS8-11198 (Unclassified).

Illustrations, graphs, and tables referenced in Volume II of the Interplanetary Navigation and Guidance Study are presented.

393. Philco Corporation, Palo Alto, California,
THE SCHEDULE OF MEASUREMENTS FOR ANALYSIS OF AN ONBOARD NAVIGATION SYSTEM by P. J. Rohde, 15 October 1965, NASA CR-61107, N66-10690, Contract NAS8-11198 (Unclassified).

This document is concerned with the selection of a measurement schedule for an onboard navigation system. The instrument which is considered to be of interest is the sextant or theodolite. Three sets of auxiliary schedule data are presented to act as engineering guides in the selection of stars and planetary bodies along the trajectory of interest. The use of this auxiliary data is demonstrated along a round trip Mars trajectory and a lunar trajectory. The value of using the auxiliary data as a guide is verified by obtaining tracking schedule evaluation data from a digital computer simulation of an onboard tracking system.

394. Satyendra, K. N.,
TRENDS IN SPACE NAVIGATION, Proceedings on Institute of Radio Engineers (USA), Vol. 50, No. 5, May 1962, pp. 1362-1373.

A figure of merit, called the self-containment index is defined to define quantitatively the degree of autonomy for which a system design is directed. The navigational problem of spacecraft is divided into problems of point-dynamics and rigid-body dynamics and the major factors are defined which deserve consideration in the understanding of the space navigational problem. Consistent with the requirements for low size, weight and power allocations and for very high accuracy and reliability tolerances, optical techniques are found ideally suited for space navigation. Open-loop and closed-loop methods of Earth satellite navigation are presented and extended to the lunar navigation problem. Some advanced navigational concepts are given using nonrotating and track-while-scan instruments. The importance is emphasized of

the increase in data-processing requirements and their part in accuracy enhancement through statistical techniques. A review of optical Doppler and lasers for measurement of distance and velocity is given. The concept of guidance management is proposed for consolidation of all the launch, orbital, midcourse, return and other guidance phases of a future multistage spacecraft into a single, integrated, self-contained navigation system within the final upper stage.

395. Schoonmaker, P. B.,
AN AUTONOMOUS-NAVIGATION EXPERIMENT FOR MANNED SPACECRAFT, New York, American Institute of Aeronautics and Astronautics, 1965, pp. 171-176, A66-11630 (American Institute of Aeronautics and Astronautics, Manned Space Flight Meeting, 4th, St. Louis, Missouri, 11-13 October 1965, Technical Papers, A66-11613).

Current interest in autonomous spacecraft navigation systems stems from the obvious weaknesses of the conventional ground-dependent navigation philosophy. Although intensively studied, the autonomous navigation concept has not yet been proved out by tests in orbit. This paper describes an experimental program to generate the needed "field" results. The emphasis is on simple, low-cost system configurations for installation on currently available manned space vehicles. Navigation data are processed by a "Schmidt-Kalman" optimal filtering program in the spacecraft's digital computer, which is augmented with a small tape unit to avoid interference with other mission requirements. The theory of optimal filtering is briefly explored, to illustrate the importance of such characteristics as accuracy, sensitivity, and data-rate. Application of these criteria results in selection of star/local vertical observations as the primary navigational mode. Navigation procedures are given for three different data-taking methods, using star/local vertical inputs.

396. Smith, G. L. and McLean, J. D.,
MIDCOURSE NAVIGATION FOR MANNED LUNAR MISSION, Society of Automotive Engineers, Paper 513E for meeting 3-6 April 1962, 21 pp.

A study of midcourse guidance for manned lunar missions at Ames Research Center resulted in a concept for a feasible guidance system; basic system requirements, design approach, and features that onboard system must include; results of

digital computer simulation showing that system could provide excellent guidance; and system gives optimal estimate of spacecraft's position and velocity at all times with onboard computer.

397. Snead, J. C.,
AN INVESTIGATION OF NOISE AND BIAS EFFECTS ON DOPPLER-INERTIAL NAVIGATION SYSTEM ACCURACY (M.S. Thesis), June 1965, 135 pp., GGC/EE/65-13, AD-619972, N66-10864.

An analytical investigation is performed to determine and compare the performances of four second-order and third-order Doppler-inertial navigation system configurations when subjected to sensor errors. This is done by determining the steady-state rms velocity output error due to noise and bias inputs for the gyro and Doppler radar and by determining the characteristics of the transient error in velocity due to step inputs of accelerometer, gyro, and Doppler bias. Simulation of the system error models in block diagram form is accomplished by Midas programming of a digital computer. The noise analysis simulation is based on the assumption that the random process is ergodic and representable by an exponential autocorrelation function. The results indicate that system performance is highly dependent upon the manner of utilizing the mixed Doppler-inertial velocity information in feedback loops and upon the dynamic response characteristics required of the system. Midas digital simulation was found to be a useful analytical tool for studies of this nature.

398. Space Technology Laboratories, Inc., Redondo Beach, California,
SYSTEMS ANALYSIS OF TRAJECTORIES AND GUIDANCE FOR A SPIN-STABILIZED LUNAR PHOTOGRAPHIC SPACECRAFT FINAL REPORT (U) 1 May 1963, STL-8536-6002-RC-000, NASA CR-62408, X65-14557, Contract NASw-621 (Confidential).

Not abstracted.

399. Stearns, E. V. B. and Carson, J. A.,
NAVIGATION REQUIREMENTS FOR MANNED PLANETARY MISSIONS, Washington, Institute of Navigation, 1965, pp. 71-107, A66-11317, Contract NAS8-5024 (Navigation for Manned Space Flight, 1964 Space Navigation Conference, St. Petersburg, Florida, 30 April and 1 May 1964, A66-11314).

Report of a study conducted for the Marshall Space Flight Center during 1962 to 1963 under Contract NAS8-5024. Various possible missions which might be conducted during the 1970's are summarized and compared, including Stopover in Orbit about Mars and Venus, Multiplanet Flyby, and Single Planet Flyby. Planetary landing on either Mars or Venus is not treated, being classed as beyond present technological capabilities during the early 1970's. Discussed are orbit determination and path corrections, sensor selection and functional systems, navigation references available, and assignment of man-machine roles. This latter topic includes a treatment of machine reliability and compares the reliability of manned with unmanned systems. Utilizing data from the X-15, Bomarc, Program 162, Mercury, Regulus, and Russian experience, it compares the capability of man and machine in several aspects and describes the benefits to be obtained by utilizing the best characteristics of each.

400. Stevens, F.,
SPACE NAVIGATION BY STAR AND PLANET TRACKING TECHNIQUES, IRE 5th National Symposium on Space Electronics and Telemetry Transactions, 1960, 16 pp.

Feasibility of light weight, high-performance optical guidance and control system for spacecraft is established in terms of hardware designs representative of state of art; principles of star and planet tracking are outlined; and design solutions to problems such as partial illumination and oblateness are presented.

401. Tatz, A.,
SPACESCAN - RADIO BROADCAST SYSTEM OF SPACE NAVIGATION, American Astronautical Society, Advances in Astronautical Sciences, Vol. 11, 1962, pp. 369-396.

Discussed are details of system of navigation guidance with total volume coverage for onboard space position measurement of geographical position, velocity, and path angle for orbit, reentry, and recovery of manned vehicles; SPACESCAN provides system of radio navigation aids that broadcast position signals useful in forming space position, three-dimensional grid with total volume radio coverage; and vehicle equipment determines its position in grid radiated from Earth-based sites over volume scanning plane beams.

402. Taylor, R. L.,
EFFECT OF OBSERVATION UNCERTAINTIES ON THE PERFORMANCE OF A PREDICTIVE GUIDANCE SYSTEM USED FOR DESCENT FROM LUNAR ORBIT, New York, American Institute of Aeronautics and Astronautics, 1964, pp. 96-110, A65-10692, Contract NASw-460 (American Institute of Aeronautics and Astronautics and NASA, Manned Space Flight Meeting, 3rd, Houston, Texas, 4-6 November 1964, Technical Papers, AIAA Publication CP-10).

Included is a study of the effects of navigation and control sensor errors on the performance of a lunar landing vehicle using a given guidance technique during the descent phase of the mission. Error sensitivity coefficients are determined which can be used to obtain an upper limit on the terminal state errors caused by noisy navigation and control sensor information. The numerical values of these coefficients are found for a given mathematical model of the navigation, guidance, and control systems. A sample computation is made which illustrates the use of these coefficients and indicates the type of information which can be obtained from their application.

403. Traenkle, C. A.,
MIDCOURSE NAVIGATION FOR INTERPLANETARY SPACE TRAJECTORIES (Mittkursnavigation für Interplanetare Raumtrajektorien), Zeitschrift für Flugwissenschaften, Vol. 12, September 1964, pp. 340-348, A64-26628 (In German).

Included is a discussion of the problem of reaching a target planet or its sphere of influence by a single impulse trajectory, with emphasis on errors occurring in the initial velocity or impulse vector when the space vehicle is injected into the transfer trajectory. It is shown that the problem of determining the foreseeable trajectory deviations at the target planet and of compensating them to zero instantly by velocity corrections on the vehicle can be solved optimally by applying certain correction impulses to the vehicle at certain angles relative to the path tangent and spaced in a certain sequence of correction stations along the trajectory. Formulas for the correction sequences are derived for the case of small deviations. The mean velocity sum of the correction kicks, corresponding to the propellant reserve for correction maneuvers, is found to be small as compared to the basic velocity sum of the mission. The formulas are numerically computed and discussed, using as an example a round trip from Earth to the target planet Mars on a Hohmann trajectory.

404. University of Michigan, Institute of Science and Technology, Ann Arbor, Michigan,
AN INTRODUCTION TO CELESTIAL MECHANICS by W. Kaplan, April 1961, Mich U Misc 6 (Unclassified).

Not abstracted.

405. University of Michigan, Willow Run Laboratories, Ann Arbor, Michigan,
LINE OF SIGHT CRITERIA FOR INTERPLANETARY NAVIGATION by T. L. Connors, W. A. Hugget, and A. C. Lawson, Jr., Michigan U-BT-4 (Unclassified).

The choice of a principle of navigation for interplanetary space travel is usually guided by the search for minimum-fuel orbit, or for a minimum fuel correction for navigational errors. Navigational techniques proposed in this paper require more fuel, but substantially reduce the complexity of the navigational task. The proposed techniques, called line-of-sight techniques, require only that the vehicle remain on a

specific line in space. No calculations of vehicle orbits or measurements of the position or velocity of the vehicle are required. Two line-of-sight techniques are considered.

406. Van Cott, H. P.,
AN OPTICAL SYSTEM FOR MANNED VEHICLE TERMINAL GUIDANCE, Human Factors, Vol. 5, June 1963, pp. 329-333, A64-10635.

Included is a description of a manual lunar reference point tracking system for implementing vehicle terminal guidance for a soft lunar landing. The system, involving onboard optical, inertial, and radio altimeter equipment, uses an onboard tracking telescope and radio altimeter to track a fixed lunar feature. The rate of change in the angle of the telescope which occurs as a result of tracking provides information for detecting and nulling lateral velocity. Navigation equations are presented.

407. Weems, P. V. H.,
PILOT CLASS IN SPACE NAVIGATION AT THE NAVAL ACADEMY: A REPORT, Navigation, Vol. 9, Winter 1962-1963, pp. 259-269, A63-14003.

Included is a discussion of the findings and recommendations of the Pilot Class in Space Navigation. The class activities are reviewed, including the preparation of the Space Navigation Handbook. The space navigation principles involved are based on the practical application of known physical laws and the small amount of information gleaned from space probes. Position-finding techniques are outlined, and the suggested timepiece, sextant, and almanac are described. The navigation procedures to be used during different phases of the space voyage are noted.

408. Welch, J. D.,
AN OPTICAL-INERTIAL SPACE NAVIGATION SYSTEM, Astronautics and Aeronautics, Vol. 3, June 1965, pp. 90-94, A65-28762.

Included is a description of a combination of advanced inertial and electro-optical sensors which provide a novel approach to the design of an autonomous space navigation system. The system is capable of providing navigation and guidance, during all phases of a space mission, including

boost, corrective maneuvers, unpowered orbital or deep-space flight, rendezvous operations, terminal guidance, and reentry. It can be fully automatic or crew operated. Its design is based on the capabilities of such advanced components as free-rotor electrostatic gyros, a dual-mode image-tube tracker, a new type of electrostatic accelerometer, and an advanced navigation-guidance computer. Three configurations are considered: (1) the body-mounted configuration, (2) the gimbaled configuration, and (3) the tethered configuration. The operation of the navigator for a typical space mission is described; it involves a prelaunch phase, a launch phase, and the stellar acquisition and alignment of the sextant navigator. It is concluded that the basic concepts presented can assume many variations. Active ranging devices could be mounted with the sextant for precise close-in terminal maneuvers. Other optical sensors and other configurations could be employed. Advanced free-rotor gyros, such as those using cryogenic principles, could be used instead of electrostatic gyros.

409. Welch, J. D.,
OPTICAL-INERTIAL SPACE NAVIGATION SYSTEM, Astronautics and Aeronautics, Vol. 3, No. 6, June 1965, pp. 90-94.

Included is a description of autonomous space navigation system which is capable of providing navigation and guidance during all phases of space mission, including boost, corrective maneuvers, unpowered orbital or deep-space flight, rendezvous operations, terminal guidance, and reentry. The system can be either fully automatic or crew-operated. Free-rotor electrostatic gyros, dual-mode image tube-tracker, new type of electrostatic accelerometer, and an advanced computer makes up a system which can assume specific configurations (body-mounted, gimbaled, or tethered), depending upon vehicle and mission requirements.

410. Westinghouse Electric Corporation, Baltimore, Maryland,
STUDY AND ANALYSIS OF ADVANCED SPACEBORNE DETECTION, TRACKING, AND NAVIGATION SYSTEM, PART II-ANALYTICAL SOLUTION, FINAL REPORT, April 1963, NASA CR-55075, N64-13013, Contract NASw-469 (Unclassified).

Sensor and guidance control methods are selected; sensor measurement accuracies are specified after, and on the basis

of, a study and evaluation of the resulting system performance. As a part of the analysis, control and data processing methods and mathematical techniques are considered, selected, and evaluated, and digital programs employed are presented and discussed.

411. Zboril, F. R.,
EFFECT OF PLANET ROTATION ON SPACE DOPPLER NAVIGATOR DATA, IRE National Symposium on Space Electronics and Telemetry, Transactions, Paper 5.4, 1962, 8 pp.

Computation of vehicle velocity with respect to center of planet is affected by introduction into radar Doppler-return of component due to rotational velocity of planet surface which is being illuminated by vehicle's radar beam. Planet-rotation effect is directly proportional to distance between planet center and vehicle and is not related to planet radius alone.

412. Abzug, M. J.,
ON THE STABILITY OF A CLASS OF DISCONTINUOUS ATTITUDE CONTROL SYSTEMS, AIAA Journal, Vol. 1, August 1963, pp. 1910-1911, A63-20495.

Included is an examination of the stability, under external torque, of attitude control systems having fixed minimum-impulse bits delivered at unsymmetrical vertical switch lines. A difference equation is obtained for successive intersections of a single switch line. The Liapunov method is used to show that any steady external torque causes instability.

413. Acord, J. D. and Nicklas, J. C.,
THEORETICAL AND PRACTICAL ASPECTS OF SOLAR PRESSURE ATTITUDE CONTROL FOR INTERPLANETARY SPACECRAFT, American Institute of Aeronautics and Astronautics, Guidance and Control Conference, Cambridge, Massachusetts, 12-14 August 1963, Paper 63-327, 12 pp., Contract NAS7-100, A63-20599.

This study considers a practical attitude control system which utilizes forces generated by solar pressure. The theory of photon momentum transfer to the exposed surfaces is briefly analyzed, and an engineering derivation of the essential equations and parameters for dealing with the resulting forces is presented. Various configurations of spacecraft equipment and control surfaces are examined as to magnitudes and directions of solar pressure torques and the necessary conditions for control. A particular spacecraft configuration is chosen for further examination and analysis to illustrate the principles involved. Block diagrams and transfer functions are given for several control and damping loop configurations. Some of the major system integration considerations are discussed, with particular emphasis on a minimum-interface combination of the solar pressure control system with an impulsive mass expulsion system. System parameter optimization by graphical parametric analysis is illustrated using the combined impulsive-solar pressure system as an example.

414. Acord, J. D. and Nicklas, J. C.,
THEORETICAL AND PRACTICAL ASPECTS OF SOLAR PRESSURE ATTITUDE CONTROL FOR INTERPLANETARY SPACECRAFT, Progress in Astronautics and Aeronautics, Vol. 13, 1964, pp. 73-101.

Various configurations of spacecraft equipment and control surfaces are examined as to magnitudes and directions of solar pressure torques and necessary conditions for control; particular spacecraft configuration is analyzed to illustrate principles involved; block diagrams and transfer functions for several control and damping loop configurations; and system parameter optimization by graphical parametric analysis is illustrated using combined impulsive-solar pressure system as example.

415. Adaptronics, Inc., Alexandria, Virginia,
SELF-ORGANIZING SPACECRAFT ATTITUDE CONTROL, FINAL REPORT, 15 JUNE 1964-30 JUNE 1965 by R. L. Barron, S. Schalkowsky, J. M. Davies, and R. F. Snyder, September 1965, AFFDL TR-65-141, AD-475 167, Contract AF-33(615)-1864, AF-8225 822508 (Unclassified).

Results are presented from an investigation of self-organizing attitude control and stabilization for spacecraft. Self-organizing control (SOC) is achieved through high-speed assessments of performance values of successive random experiments with respect to a generalized control criterion, followed by a reward-punishment reinforcement process to obtain on-line synthesis of plant actuation signals. The logic is of the probability state variable (PSV) type, i.e., reinforcement signals are used to bias the probabilities associated with the SOC experiments. Convergence of SOC output signals to appropriate, time-varying levels generally occurs within several milliseconds, resulting in rapid, well damped stable control over a very wide range of controller, plant, and disturbance characteristics (including induced artificial failures). A laboratory experimental self-organizing controller has been fabricated. Evaluations of this SOC have been conducted using single-axis analog computer simulations of a representative orbital vehicle. Compared to a conventional controller for this vehicle, the SOC produced superior transient and comparable steady-state performance. The SOC adapted to a range of plant characteristics over which the conventional controller did not provide uniformly satisfactory performance.

416. Aerospace Corporation, Los Angeles, California, A QUANTIZED DATA ATTITUDE CONTROL SYSTEM by P. R. Dahl, V. R. Brenes, and H. Sokoloff, June 1964, TDR269-4116-46-1, SSD, TDR64-104, AD-448 063, Contract AF-04(695)-269 (Unclassified).

A space vehicle attitude control system that utilizes a quantized attitude error signal is presented. The quantized attitude information is passed through a lead compensation network comprised of passive electronic elements. The lead network response to an input, consisting of a series of quantization steps, is a series of exponentially decaying pulses that, in turn, are fed into a biased Schmitt trigger circuit. The Schmitt trigger circuitry activates an on-off torque-producing device which applies corrective torques to the vehicle. Analyses of system operation are presented, including the general solution for the lead network response to a uniform staircase input. The staircase solution is used to derive expressions for the single pulse on and off switching. Lines are shown to describe the regions of pulsing torque application. Acquisition and limit cycle modes of operation are analyzed to determine the nature of the response trajectories. Although the control system is quite simple in philosophy and mechanization and does not require mode switching, it is shown to have desirable response characteristics over its entire dynamic operational range.

417. Aerospace Corporation, Los Angeles, California, FLUID FLYWHEEL ATTITUDE CONTROL SYSTEM STUDIES by D. J. Griep, TOR-269(4540-70)-5, AD-606 316, Contract AF-04(695)-269 (Unclassified).

A single-axis attitude control system using a fluid-flywheel as the torque-producing element is analyzed. The control laws that are either analyzed or derived are: (1) proportional control, (2) minimum orientation time control, and (3) minimum electrical-power consumption control. Pontryagin's maximum principle was used to derive the latter two control laws. Experimental laboratory data are presented for the proportional control system. The smooth, low-velocity performance obtained using a fluid flywheel is demonstrated.

418. Air Force Cambridge Research Laboratory, Cambridge, Massachusetts,
ELECTROMAGNETIC CONTROL OF THE ATTITUDE OF SPACE VEHICLES, TECHNICAL REPORT by P. Bruscaglioni and A. Consortini, December 1962, AFCRL-63-83, N63-14820, Contract AF-61(052)-536 (Unclassified).

A theoretical investigation has been made of the possibility of applying the properties of elliptically polarized waves to the attitude control of space vehicles. Three different ways of applying electromagnetic radiation have been discussed. The first one employs an antenna on a space vehicle which radiates with circular polarization. The second one makes use of the torque experienced by a receiving antenna on the vehicle when a ground station radiates toward the vehicle. The third one is based on the simultaneous and tuned emission of radiation from an antenna located on the vehicle and from a ground antenna. A comparison between the torque which can be obtained and the torques necessary to the control of the attitude of a space vehicle in actual situations shows that the first procedure can have practical importance, while the torques obtained by means of the second and third procedures are too weak.

419. Air Force Systems Command, Wright-Patterson Air Force Base, Ohio,
AN INTEGRATED FLIGHT CONTROL SYSTEM FOR MANNED ADVANCED AERONAUTICAL AEROSPACE VEHICLES (U) 11 February 1963, AFSC 63ASRM-691 (Confidential).

Not abstracted.

420. Air Force Systems Command, Wright-Patterson Air Force Base, Ohio,
CONTROLLING A SPACESHIP by M. Litvin-Sedoy, X65-36240, (Aviation and Cosmonautics, Special Issue, 1964, pp. 65-82, X65-36239, pp. 18-30 (Unclassified).

Not abstracted.

421. Air Force Systems Command, Wright-Patterson Air Force Base, Ohio,
FLIGHT CONTROL, November 1965, RTD-67-17 (Unclassified).

Not abstracted.

422. Alekseev, K. B. and Bebenin, G.G.,
SPACECRAFT CONTROL (Uprevlenie Kosmicheskim Letatel'nym Apparatom) Moscow, Izdatel'stvo Mashinostroenie, 1964, 403 pp.(In Russian) A65-11616.

The monograph, intended primarily for a wide circle of engineers and designers working in the field, familiarizes the reader with the basic principles of spacecraft control. Divided into three sections, spacecraft as an object of control, elements of control systems, and the principles of construction and examination of control systems, it offers a comprehensive review of theoretical and technical aspects of the subject. Chapters 1-3 set forth the fundamental laws of mass center motion, the dynamics of spacecraft angular motion, and passive stabilization of space vehicles. The principles of design and operation of control devices and measuring equipment are discussed in Chapters 4-6, while technological aspects and technical materialization of the devices and equipment are dealt with in Chapters 7-10. The problems of reentry and landing are briefly discussed in Chapter 10. Special attention is given to the theoretical aspects of the measuring of motion parameters and spacecraft angular motion control.

423. Andeen, R. E. and Shipley, P. P.,
DIGITAL ADAPTIVE FLIGHT CONTROL SYSTEM FOR AEROSPACE VEHICLES, AIAA Journal, Vol. 1, No. 5, May 1963, pp. 1105-1109.

The system uses identification and synthesis processes to determine what changes in control parameters are required to adapt to changes in dynamics of vehicle as it experiences wide range of flight conditions; identification of vehicle dynamics is accomplished by improved identification technique; and digital computer simulation of digital adaptive pitch rate flight control system was performed which included identification of fourth-order aerospace vehicle and actuation system and synthesis of fourth-order digital compensator.

424. Archer, W. D.,
DESIGN STUDY OF A DEVICE TO DEMONSTRATE DYNAMIC PERFORMANCE OF SPACECRAFT, IEEE Transactions on Aerospace, Vol. AS-1, August 1963, pp. 795-802 (Institute of Electrical and Electronics Engineers, International Conference and Exhibit on Aerospace Support, Washington, D.C., 4-9 August 1963) A63-23294.

Included is a description of the study of a device capable of mounting a spacecraft for demonstration and training in dynamic performance of spacecraft control systems. The objectives of the study are outlined, and the analysis and conclusions of an investigation of each of five separate systems are discussed. These systems are: gas bearing sphere, off-board wheel-supported sphere, onboard multiwheel system, onboard steerable-wheel system, and servo driven gimbal. The wheeled device rotating in a hemispherical contoured base proved to be adequate.

425. Army Ballistic Missile Agency, Guidance and Control Laboratory, Huntsville, Alabama,
A COMPARISON OF SOME ACTUATION METHODS FOR ATTITUDE CONTROL OF SPACE VEHICLES by W. Haeussermann, 10 November 1959, ABMA DG-TN-63-59 (Unclassified).

The manifold individual attitude control requirements of each particular space vehicle are confronted with a great variety of actuation methods for attitude control which are available today, or which seem to be feasible in the near future. This paper describes the different actuation methods and presents system characteristics such as control mode data and control torques in view of their contribution to weight, power, volume, and lifetime considerations for the space vehicles. (To be presented at The National Symposium on Manned Space Stations, sponsored by the IAS with the cooperation of NASA and the Rand Corporation, to be held in Los Angeles, 20-22 April 1960.)

426. Army Ballistic Missile Agency, Guidance and Control Laboratory, Huntsville, Alabama,
AN ATTITUDE CONTROL SYSTEM FOR SPACE VEHICLES by W. Haeussermann, ABMA RT-10 (Unclassified).

The attitude control system for a space vehicle must be designed to meet requirements which differ so much from those

of the control system for the booster stages that independent control systems will be preferable for both applications. Some of the major requirements for a three-axis attitude control system for a space vehicle are summarized. The proposed attitude control system is explained, and control system characteristics are discussed.

427. Army Ballistic Missile Agency, Guidance and Control Laboratory, Huntsville, Alabama,
FEASIBILITY STUDY OF AN ATTITUDE CONTROL SYSTEM FOR SPACE VEHICLES by H. F. Kennel and G. P. Drawe, 6 April 1959, ABMA DG-TM-17-59 (Unclassified).

This report presents the results of a feasibility study of an attitude control system for space vehicles. A general requirement for such a system is that it has to operate a considerable length of time in contrast to the systems presently in use. Power consumptions and weight considerations are, therefore, of utmost importance. The only satisfactory solution for such an application is a control system which utilizes restoring forces without the expenditure of mass. The proposed system uses the inertial reaction torques of three accelerated flywheels, one for each of the mutually perpendicular axes.

428. Army Ballistic Missile Agency, Guidance and Control Laboratory, Huntsville, Alabama,
THE SPHERICAL CONTROL MOTOR FOR THREE AXIS ATTITUDE CONTROL OF SPACE VEHICLES by W. Haeussermann, 23 October 1959, ABMA DG-TM-59-59 (Unclassified).

A spherical reaction member for a three-axis attitude control is described and compared with the common one-axis flywheel system. Special problems are considered; such as, control of the space vehicle with the spherical reaction member, torquing the sphere, supporting it by a bearing, and measuring its speed.

429. Aseltine, J. A.,
AEROSPACE CONTROLS TODAY, ISA Journal, Vol. 12, September 1965, pp. 82-87.

Not abstracted.

430. Author Unknown,
ACCESSORY COMPONENTS: STATE OF THE ART, Space/Aeronautics, Vol. 38, No. 2, 1962-1963, pp. 3-8.

Not abstracted.

431. Author Unknown,
ALL-ATTITUDE DISPLAY FOR APOLLO COMMAND MODULE, Space/Aeronautics, Vol. 41, May 1964, p. 99.

Not abstracted.

432. Author Unknown,
GRAVITY GRADIENT STABILIZATION SYSTEM SUCCESSFULLY FLOWN, Franklin Institute Journal, Vol. 277, April 1964, p. 381.

Not abstracted.

433. Author Unknown,
RESEARCHERS TUNE UP HARDWARE FOR DEEP SPACE, Machine Design, Vol. 34, 6 December 1962, p.10.

Not abstracted.

434. Author Unknown,
WHICH IS BEST FOR AEROSPACE CONTROL POWER, Machine Design, Vol. 34, 22 November 1962, pp. 139-141.

Not abstracted.

435. Barron, R. L., Schalkowsky, S., D ies, J. M., and Snyder, R. F.,
SELF-ORGANIZING ADAPTIVE SYSTEMS FOR SPACE VEHICLE ATTITUDE CONTROL, American Institute of Aeronautics and Astronautics, 1965, pp. 163-173, (AIAA/ION Guidance and Control Conference, Minneapolis, Minnesota, 16-18 August 1965, A66-10001, A66-10019, Contract AF-33(615)-1864.

Results from an Air Force sponsored investigation of self-organizing attitude control and stabilization for spacecraft are included. Self-organizing control (SOC) is achieved through high-speed assessments of performance values of

successive random experiments with respect to a generalized control criterion, followed by a reward-punishment reinforcement process used to obtain on-line synthesis of plant actuation signals. The logic is of the Probability State Variable (PSV) type, i.e., reinforcement signals are used to bias the probabilities associated with the SOC experiments. Convergence of SOC outputs to appropriate (time-varying) signal levels generally occurs within several milliseconds, resulting in rapid, well damped, stable control over a very wide range of plant and disturbance characteristics. Laboratory experimental self-organizing controllers have been fabricated. Evaluations of these SOC systems have been conducted using analog computer simulations of representative space vehicle control system configurations. Compared to a conventional controller the SOC system produces superior transient and comparable steady-state performance. The SOC system adapts to a range of plant characteristics over which the conventional controller does not provide uniformly satisfactory performance. Potential performance and reliability improvements realizable through extension of SOC techniques are discussed.

436. Bendix Corporation, Southfield, Michigan, HIGH MOMENT PRODUCING TECHNIQUES FOR ATTITUDE CONTROL AND STABILIZATION OF MANNED SPACE VEHICLES, VOLUME I, MOMENT REQUIREMENTS AND TECHNIQUES by S. Bendix, February 1963, ASD TDR62 737, AD-401 747, Contract AF-33(657)-7409 (Unclassified).

Included are high moment producing techniques for attitude control and stabilization of manned space vehicles.

437. Besco, R. O., HANDLING QUALITIES CRITERIA FOR MANNED SPACECRAFT ATTITUDE CONTROL SYSTEMS, American Institute of Aeronautics and Astronautics, 1964, pp. 271-275, (American Institute of Aeronautics and Astronautics, and NASA, Manned Space Flight Meeting, 3rd, Houston, Texas, 4-6 November 1964, Technical Papers, AIAA Publication CP-10), A65-10710.

Included is a presentation of general performance criteria for attitude-control systems, which can be used for all types

of manned vehicles and missions. The fundamental characteristics of the angular acceleration response provided by an attitude-control system are shown to be the amplitude, duration, initiation time, frequency, and direction of the response. Two handling parameters are derived from these basic characteristics: they are the torque advantage rate, defined as the ratio of available versus required torque, and the control system authority, defined as the torque versus inertial ratio incorporating a duty cycle correction. Simulation studies indicate the advantages of using these parameters.

438. Boeing Co., Seattle, Washington,
COMPARISON OF SPACECRAFT MANEUVERING CONTROL SYSTEMS EMPLOYING STRAP-DOWN GYROS by C. H. Henrikson and G. A. Price, August 1965, D2-23254-Rev-A, AD-468 712 (Unclassified).

An examination was made of spacecraft attitude maneuvering systems in which strap-down gyroscopes are used for inertial reference. No new schemes were proposed but three existing schemes were examined. These were: the system now used in the Ranger and Mariner spacecraft and two methods proposed for use in the Lunar Orbiter. Evaluation of the three systems was based primarily on accuracy. Error categories were defined and a sample calculation of total system pointing error was performed. Results are based on one set of example systems and are not conclusive in themselves. Some general conclusions may be drawn, however: (1) maneuvers should be made as rapidly as possible consistent with fuel available and gyro capability, (2) although the Ranger/Mariner scheme has been used successfully in practice, somewhat improved performance is possible by use of either of the two Lunar Orbiter schemes, and (3) in addition to requiring a precision gyroscope, each system also requires either a precision command device (torquing current generator) or a precision readout device (integrator). In respect to complexity, weight, and fuel consumption, the three attitude maneuver methods are roughly equivalent.

439. Bouvier, H. K.,
THE MARINER - IV ATTITUDE CONTROL SYSTEM, Sciences et Industries Spatiales, Vol. 1, No. 7-8, 1965, pp. 41-48, A66-12480.

Included is a discussion of the three-axis control system of Mariner IV, and of its capability to perform a midcourse maneuver for trajectory refinement. Attitude control about two axes was necessary for sun orientation so as to control temperature and to generate solar power. Complete attitude control about three axes was required to make communication possible, to orient scientific instruments, and to establish a reference system for the orientation of the midcourse motor thrust vector. A new system of solar radiation control was tested. It is considered that the flight demonstrated that problems which could not have been foreseen can be solved if the systems are adaptable to new circumstances.

440. Bowers, J. C. and Vieth, R. V.,
HYBRID ANALOG-SWITCHING ATTITUDE CONTROL SYSTEM FOR SPACE VEHICLES (HYACS), National Electronics Conference - Proceedings, Vol. 19, 1963, Paper 1619, pp. 249-260.

Attitude control system for space vehicles affording minimum fuel consumption, maximum speed of response or any preselected trade-off is described; adaptive version provides control in the presence of such characteristic operating conditions as inertia changes, control torque variations, and disturbance torques; design accommodates changes in th .st to inertia ratio by a factor of 5:1; system is small, light and consumes little electrical power; and unique circuit arrangement permits less than 0.005-degree attitude switching hysteresis and virtually eliminates logic box switching time delays.

441. Bruscaglioni, P., Consortini, A., and Di Francia, G. T.,
ELECTROMAGNETIC CONTROL OF THE ATTITUDE OF SPACE VEHICLES, I. THEORY, Alta Frequenza (Italy), Vol. 32, No. 11, November 1963, pp. 768-780 (156E-168E).

A theoretical investigation into the possibility of using electromagnetic waves for the application of control torques to space vehicles is included. It is pointed out that while for

quick maneuvers large torques are required; for some purposes very small torques would be sufficient. Elliptically polarized electromagnetic waves carry an angular momentum about the direction of propagation and the effect of such waves on a transmitting aerial and a receiving aerial are theoretically investigated.

442. Bruscaglioni, P., Consortini, A., and Di Francia, G. T., ELECTROMAGNETIC CONTROL OF THE ATTITUDE OF SPACE VEHICLES, II. PRACTICAL APPLICATIONS, Alta Frequenza (Italy), Vol. 32, No. 11, November 1963, pp. 781-789 (169E-177E).

Having calculated the torques obtainable from an aerial radiating elliptically polarized waves and from an aerial receiving such waves, or doing both at once in a synchronized manner, in Part I (preceding abstract), Part II proceeds to the calculation of torques likely to be required in practice. These are based largely on existing satellites and it is shown that only the first (active) method is likely to have practical possibilities.

443. Burlingham, C. S. and Daubert, H. C., Jr., DIGITAL ATTITUDE CONTROL SYSTEM FOR SPACECRAFT, North Hollywood, California, Western Periodicals Co., 1963, pp. 1.5.1-1 to 1.5.1-10, A64-18278 (Annual East Coast Conference on Aerospace and Navigational Electronics, 10th, Baltimore, Maryland, 21-23 October 1963, Proceedings).

Included is an experimental evaluation of a stabilization and control system in which digital methods are used for measurement, signal processing, and torque control. The logic design of the control system is discussed in detail, and the hardware used for implementing the design is described. Preliminary experimental results are presented which confirm predicted control accuracy advantages. It is concluded that this control system is for a hypothetical spacecraft and permits a variety and precision of control which would probably not be required by operational spacecraft. A reduction in required modes of operation would result in a simplification of controller electronics. It is stated that, however, a requirement for greater accuracy can also be met, subject practically only to the null accuracy limitations of the primary sensor and the size of the encoder position pickoff.

444. Burlingham, C. S. and Daubert, H. C., Jr.,
DIGITAL TECHNIQUES FOR AN ATTITUDE-CONTROL SYSTEM, Electro-Technology, Vol. 73, April 1964, pp. 34-38.

Not abstracted.

445. Burrow, J. W.,
MOMENTUM DUMPING USING MAGNETIC TORQUES, ARS Journal, Vol. 31, December 1962, pp. 1776-1778.

Not abstracted.

446. Byrne, B., Murphy, W., and Lanzkron, R. W.,
GIMBALLESS INERTIAL REFERENCE SYSTEM, IRE International Convention Record, Vol. 10, Pt. 5 (Aerospace and Navigational Electronics, etc.), 1962, pp. 163-174.

Included are design requirements for vehicle which uses as its inertial reference gimballess electronic inertial package; system consists of three strap-down (body mounted) rate gyros, three accelerometers, and one digital differential analyzer; output of this package is equivalent to outputs of conventional gimbaled inertial platform; and an example is worked out in detail.

447. Cannon, R. H., Jr.,
BASIC RESPONSE RELATIONS FOR ATTITUDE CONTROL USING GYROS, Joint Automatic Control Conference, 19-21 June 1963, pp. 645-646.

Relations are presented for space vehicle attitude control systems employing single-axis gyros. Systems are compared with those using reactor wheels.

448. Cannon, R. H., Jr.,
GYROSCOPIC COUPLING IN SPACE VEHICLE ATTITUDE CONTROL SYSTEMS, AMSE Transactions, Vol. 84, March 1962, pp. 41-53.

Not abstracted.

449. Cannon, R. H., Jr.,
SOME BASIC RESPONSE RELATIONS FOR REACTION-WHEEL ATTITUDE CONTROL, ARS Journal, Vol. 32, No. 1, January 1962, pp. 61-74.

Included are response relations, vehicle attitude, control torque, wheel motion, mechanical power, and energy consumption for space vehicle subjected to sinusoidal or impulsive disturbances; resulting normalized numerical relations serve as order of magnitude basis for preliminary design estimates and comparisons; response relations are derived for single axis model; applicability to three-axis design; and control system proposed decouples vehicle dynamics so that motions are exactly single axis.

450. Cannon, R. H., Jr. and Eppler, W. G., Jr.,
VECTOR RETICLE, CONTROL ACTION DISPLAY IN MANUAL CONTROL OF SPACE VEHICLE ATTITUDE, Journal of Spacecraft and Rockets, Vol. 2, No. 2, March-April 1965, pp. 172-182.

Two concepts, vector reticle and control action display, are proposed for making manual three-axis attitude control more efficient while reducing concentration req[illegible]ed of pilot; concepts are combined in control action reticle and in which pilot has direct control of jet valves and vector reticle which presents all auxiliary information in single three-part geometric vector, superimposed on window; control action display gives pilot instantaneous control of reticle, thus removing need for two mental integrations and reducing concentration required for tracking; and results of three-axis (fixed-base) simulation studies of system.

451. Carney, R. and Conover, T.,
DIGITAL ATTITUDE CONTROL SYSTEM, IEEE Transactions on Aerospace and Navigational Electronics, Vol. ANE-10, No. 1, March 1963, pp. 45-49.

A simple "minimum-fuel," digital attitude control system requiring no rate gyros is described; inertial guidance computer furnishes quantized attitude angle to control system; with this attitude information, and measure of time, control computer accurately computes vehicle's average rate; and novel switching zone arrangement in phase plane results in decisions controlling on-off reaction jets that adjust vehicle's attitude.

452. Cartwright, W. F. et al,
CIRCULAR CONSTRAINT NUTATION DAMPER, AIAA Journal, Vol. 1, June 1963, pp. 1375-1380.

Not abstracted.

453. Chao, W. W.,
ATTITUDE CONTROLS DEVELOPMENT AT VICKERS FOR SPACE VEHICLES AND MISSILES, Space/Aeronautics, Vol. 35, March 1961, pp. 65-66.

Not abstracted.

454. Chao, W. W.,
JET REACTION SYSTEMS FOR ATTITUDE CONTROL, Hydraulics and Pneumatics, Vol. 14, December 1961, pp. 70-71.

Not abstracted.

455. Chin, T. H.,
SPACECRAFT STABILIZATION AND ATTITUDE CONTROL, Space/Aeronautics, Vol. 39, June 1963, pp. 88-93, AD-416 078, A63-18058.

Included is a comparison of current operational and conceptual systems in terms of weight, power, and reliability. Specifically disucssed are (1) a single-axis attitude-control system using gyros as the torque source, (2) an attitude-control system using the Earth's magnetic field, (3) an on-off attitude-control system using reaction jets, (4) an inertia-wheel attitude-control system, and (5) a proposed combined attitude-control system using inertial and magnetic forces.

456. Chin, T. H.,
SPACECRAFT STABILIZATION AND ATTITUDE CONTROL, Space/Aeronautics, Vol. 39, No. 6, June 1963, pp. 88-93.

Included is a definition of terms and general requirements; attitude stabilization systems in use of under consideration rely on gravity gradients, aerodynamic forces, radiation pressure, or spin, attitude control systems on gyros, Earth's magnetic field, reaction jets, inertia wheels, reaction spheres, moving masses, Earth scanners, star or planet trackers, or combination of these devices; use of reaction spheres for

precise attitude control is new concept that offers attractive features; and suspended sphere and other feasible systems.

457. Chrysler Corporation,
A THREE AXIS STUDY FOR A FLYWHEEL TYPE ATTITUDE CONTROL SYSTEM by W. E. Davis, 30 June 1960, Chrysler PR-30 Jun 60 (Unclassified).

The major effort during this report period was the study of an attitude control system utilizing flywheel reaction torques. The single axis control loop expanded to a three axis control system and the describing equations are derived.

458. Chute, F. S. and Walker, G. B.,
POSSIBILITY OF STABILIZING SPACE VEHICLE USING ELECTROMAGNETIC ANGULAR MOMENTUM, Canadian Aeronautics and Space Journal, Vol. 11, No. 7, September 1965, pp. 219-225.

Investigation is made of possibility of controlling attitude of space vehicle by radiating electromagnetic angular momentum; control torques are produced by radiating suitably polarized waves from antenna mounted on spacecraft; two simplest arrangements consist of crossed electric or magnetic dipoles; in each case two dipoles forming cross are physically perpendicular and are driven in time quadrature; also considered is retarding torque exerted on spinning antenna; and it is shown that, while this torque is present in almost every space application, it is practically negligible.

459. Chyba, H. J.,
SURVEY OF MEANS FOR SPACE REFERENCE, ARS Journal, 15 October 1961, ARS Reprint 2247-61, 16 pp.

This paper presents some of the results of a survey to collect ideas that may contribute to the design and development of improved space reference devices. Although applications for long range missiles and for space travel were considered to be of primary importance, the investigation was made to include the more "ordinary" uses of gyros and accelerometers in aircraft, ships, tanks, and other vehicles. In this way the potentialities of any idea could be exploited to the fullest.

460. Cornille, H. J., Jr.,
YO-YO CUTS SPACECRAFT SPIN RATES, Space/Aeronautics, Vol. 39, January 1963, p. 141.

Not abstracted.

461. Cross, C. A.,
A PRACTICAL INVESTIGATION OF SPACESHIP CONTROL PROBLEMS, International Astronautical Federation, June 1959, IAF Congress 10-0/313, 11 pp.

A spaceship flight simulator has been designed, built, and successfully operated. It consists of a control panel, an electro-mechanical computer, and a planetarium type projector. A person sitting at the control panel and watching the projected display has the experience of flying a rocket-ship in interplanetary space. This relatively simple equipment has been used to investigate the techniques of manned space-flight.

462. Cubic Corporation,
FEASIBILITY STUDY FOR A VEHICLE ATTITUDE DETERMINING SYSTEM, VOLUME I - SYSTEM DESCRIPTION AND ANALYSIS, November 1964, RADC-TDR-64-318, Contract AF-30(602)-3135 (Unclassified).

Not abstracted.

463. Cubic Corporation,
FEASIBILITY STUDY FOR A VEHICLE ATTITUDE DETERMINING SYSTEM, VOLUME II - DETAILED ANALYSIS OF ANTENNAS, PROPAGATION, POLARIZATION, AND PERFORMANCE, November 1964, RADC-TDR-64-318, Contract AF-30(602)-3135 (Unclassified).

Not abstracted.

464. Dahl, P. R., Brenes, V. R., and Sokoloff, H.,
A QUANTIZED DATA ATTITUDE CONTROL SYSTEM, American Institute of Aeronautics and Astronautics, and Institute of Navigation, Astrodynamics Guidance and Control Conference, Los Angeles, California, 24-26 August 1964, Paper 64-660, A64-23830.

Included is a discussion of a system utilizing sampled error information and a passive lead compensation network. The lead network, normally used in continuous control systems, is adopted because it provides error information in a useful form. The lead network response to an input consisting of a series of quantization steps is a series of exponentially decaying pulses that, in turn, are fed into a biased Schmitt trigger circuit. The Schmitt trigger circuitry activates an on-off torque-producing device which applies corrective torques to the vehicle. Analyses of system operation are presented, including the general solution for the lead network response to a uniform staircase input. The staircase solution is used to derive expressions for the single pulse on and off switching lines in the phase plane. Envelopes of the single-pulse on and off switching lines are shown to describe the regions of pulsing torque application. Acquisition and limit cycle modes of operation are analyzed to determine the nature of the response trajectories. Although the control system is said to be quite simple in philosophy and mechanization, and although it does not require mode switching, it is indicated to have desirable response characteristics over its entire dynamic operational range.

465. Daubert, H. C., Jr.,
A SPACECRAFT DIGITAL CONTROLLER, Society of Automotive Engineers, 1965, pp. 370-376, A66-10689, Contract NASw-1004 (Aerospace Vehicle Flight Control Conference, Los Angeles, California, 13-15 July 1965, Proceedings, A66-10661).

Description of a study and experimental evaluation program performed to apply digital techniques to the problem of spacecraft stabilization and control is included. Because of the capability of extended accuracy, digital systems are indicated for guidance and control of spacecraft. Furthermore, by implementing these systems with integrated microelectronic

components, substantial improvement in reliability can be expected. Of major consideration in the program were the selection of appropriate mathematical techniques for system analysis and the development of suitable fabrication methods for hardware implementation. A discrete state model of a spacecraft reaction wheel and jet attitude control system was developed and computer simulations were performed. An electronic control unit for this system was designed, constructed with semiconductor integrated microelectronics, and tested on an air bearing simulator. The mathematical model of the system is presented and the experimental performance is compared with the computer simulation of the system.

466. DeLisle, J. E., Hildebrant, B. M., and Petranic, T. D., ATTITUDE CONTROL OF SPACE VEHICLES, ARS Journal, 15 October 1961, ARS Reprint 2114-61, 7 pp.

The first section of this paper will mention the torques acting in a space or satellite vehicle and then list the methods of sensing the resultant disturbance and providing control torques. Following this will be a description of the sensors and actuators used on some previous Earth satellites and certain of those proposed for future satellites and space vehicles. The third section will touch upon the relative merits of some of the previously mentioned devices and discuss briefly the effects of space environment upon gyro life.

467. DeLisle, J. E., Hildebrant, B. M., and Petranic, T. D., ATTITUDE CONTROL OF SPACECRAFT, Astronautics, Vol. 6, No. 11, November 1961, pp. 28 and 87-89.

Included are functions of attitude-sensing system and summary of sensing methods; inertial methods include gyro-stabilized platforms, yaw and rate gyros; principal methods using optics and radiation are celestial observation by telescope, center of illumination tracking, horizon scanning, celestial rate sensing, and velocity over height (V/H) technique; and primary methods of actuation are by use of jet, inertial reaction, and electromagnetic devices.

468. Dertouzos, M. L. and Roberge, J. K.,
HIGH CAPACITY REACTION-WHEEL ATTITUDE CONTROL, Joint Automatic Control Conference, 19-21 June 1963, pp. 428-436.

Synthesis of reaction wheel system is presented, based on exchange of angular momentum between vehicle and momentum storage elements. The system is capable of developing large vehicular rates of order 1 rad/sec and large vehicular accelerations of order 0.1 rad/sec.

469. Diamantides, N. D.,
CORRELATIONAL AND SPECTRAL TECHNIQUES IN MODERN COMMUNICATION AND CONTROL SYSTEMS, Electrical Engineering, Vol. 80, November 1961, pp. 860-865.

Not abstracted.

470. Donlin, T. J. and Randall, J. C.,
A SOLAR VANE ACTUATION SYSTEM FOR SPACECRAFT ATTITUDE CONTROL, American Society of Mechanical Engineers, Mechanisms Conference, Lafayette, Indiana, 19-21 October 1964, Paper 64 - MECH-40, A64-10602.

Included is a description of the function and detail design of a system for passive attitude control employing solar pressure. The actuation system consists of two portions: an electromechanical system which moves the vanes to balance solar pressure on the spacecraft, and a thermomechanical system which introduces solar pressure damping. Both systems are discussed in detail with parameters for a specific spacecraft. It is seen, however, that the techniques can be directly applied to any spacecraft configuration.

471. Doolin, B. F.,
SPACE VEHICLE ATTITUDE CONTROL, NASA-University Conference on Science and Technology of Space Exploration-Proceedings, Vol. 1, November 1962, pp. 381-386.

Included is a general description of attitude control systems and their elements; limitations imposed by present state of art upon some current system designs and trend followed.

472. Dutzmann, R.,
METHODS OF ATTITUDE AND DIRECTIONAL CONTROL OF SPACE VEHICLES AND THE PROBLEMS OF PRACTICAL APPLICATION (Methoden der Lenkung und Orientierung von Raumfluk und Probleme der Praktischen Anwendunc) Flug-Revue, July 1962, pp. 32-36ff. (3 p.) A63-11422 (In German).

Included is a description of several attitude and directional control methods for manned, reusable space vehicles, satellites, and ballistic bodies. Control systems using rocket-jet, cold-gas, and hot-gas systems are discussed. In addition, problems associated with the application of each of the control systems are analyzed. The systems are schematically illustrated.

473. Ergin, E. I.,
CURRENT STATUS OF PROGRESS IN ATTITUDE CONTROL, Astronautics and Aeronautics, Vol. 13, 1964, pp. 7-36.

Control system requirements are considered from performance rather than mission point of view and implications of requirements in terms of control system design; specific attitude control approaches and associated performance or implementation problems; and present test approaches to evaluate functional integrity and performance of control system are static end-to-end tests, single-axis dynamic tests, three-axis dynamic tests of scaled-down control system, and full-scale integrated spacecraft on air-bearing table.

474. Ericson, W. B. and Maciulaitis, A.,
INVESTIGATION OF MAGNETOHYDRODYNAMIC FLIGHT CONTROL, Journal on Spacecraft and Rockets, Vol. 1, No. 3, May-June 1964, pp. 283-289.

Discussed in this article are: results of investigation into use of magnetic field in nose region of hypersonic vehicle as means of flight control; vehicle is moving at speeds that cause shock-ionization of significant portion of shock layer; altitude-speed regimes in which ionized flow will strongly interact with magnetic field are determined; governing interaction parameter is based on shock standoff distance; magnetohydrodynamic control forces are computed; and it is shown that critical portion of flight path (down to 30 km and 6 km/sec) for interplanetary reentry lies well within MHD control regime.

475. Farrenkopf, R. L., Sabroff, A. E., and Wheeler, P. C., INTEGRAL PULSE FREQUENCY ON-OFF CONTROL, American Institute of Aeronautics and Astronautics, Guidance and Control Conference, Cambridge, Massachusetts, 12-14 August 1963, Paper 63-328, A63-20664.

Included is the development of a complete analytical design procedure for an integral pulse frequency on-off attitude control system. An extension of Liapunov's second method is applied to establish the domain of possible ultimate states as well as the transient convergence characteristics. Within the so-found ultimate state domain application of point-transformation techniques prove existence, stability, and uniqueness of the more important limit cycles, thereby providing an ultimate state design procedure. Comparison of the transient convergence characteristics with a suitably defined linear first approximation provides a useful engineering transient design procedure. A detailed analog simulation study complements and extends the analytical efforts by verifying the validity of the assumptions utilized and by providing useful operating characteristics not readily obtainable by tractable analysis. In particular, a detailed simulation study of the effects of noise at the controller input demonstrates the advantageous noise rejection characteristics of integral pulse frequency control over comparable bang-bang control. A generalized design procedure is presented to delineate the basic considerations in application of integral pulse frequency control to spacecraft attitude control problems.

476. Farrenkopf, R. L., Sabroff, A. E., and Wheeler, P. C., INTEGRAL PULSE FREQUENCY ON-OFF CONTROL, Astronautics and Aeronautics, Vol. 13, 1964, pp. 185-230.

Analytical design procedure is developed for integral pulse frequency (IPF) on-off attitude control system; extension of Lyapunov's Second Method is applied to establish domain of possible ultimate states, and transient convergence characteristics; application of Point Transformation techniques prove existence, stability, and uniqueness of state design procedure; results of simulation study; and generalized design procedure illustrates considerations in application of IPF control to spacecraft attitude control problems.

477. Ford, B. H.,
ANALYSIS OF FLICKER SYSTEM BY STEP-WISE INTEGRATION, ASME-Paper 63-WA-155 for Meeting 17-22 November 1963, 12 pp.

Step-wise integration method of analysis of a particular type of flicker control system is presented that is generally applicable to oscillatory type control systems, particularly to impulse systems for spacecraft control. When restrained to solutions of "reasonable complexity," method yields stability criterion, exact steady-state solutions, and approximate transient solutions.

478. Forney, R. G.,
MARINER II - ATTITUDE CONTROL SYSTEM, International Astronautical Federation, International Astronautical Congress, 14th, Paris, France, 25 September-1 October 1963, Paper 131, A63-25674, Contract NAS 7-100.

Included is a discussion of the design requirements, operation, and performance of the Mariner II attitude control system used to carry out the mission to Venus. The concept, system operation equipment, and problems are summarized as state-of-the-art for the year 1962.

479. Forney, R. G., Szirmay, S. Z., and Bouvier, H. K.,
MARINER 4 MANEUVER AND ATTITUDE CONTROL, Astronautics and Aeronautics, Vol. 3, October 1965, pp. 36-39, A66-16317.

Included is a description of the devices used aboard the Mariner 4 spacecraft to insure maneuverability and attitude control. The sun, and the star Canopus, formed the celestial frame of reference for this mission. The sun sensors for pitch- and yaw-control consist of CdS cells connected in a bridge circuit and positioned around a plane perpendicular to the axis to be controlled. Rotation about the axis increases illumination on one cell, while decreasing it on the other. The star Canopus is used to establish control about the roll axis. The principal element of the startracker is an electrostatic image-detector, the components of which are described. Inertial reference is provided by gyroscopic action. A switching amplifier establishes an on-off mode of operation. The whole attitude control system contains 1800 components. The auxiliary control supplied by the solar panel vanes is described and flight performance is discussed.

480. Freed, L. E.,
ATTITUDE CONTROL SYSTEM FOR SPINNING BODY, ARS Journal, Vol. 32, No. 3, March 1962, pp. 396-401.

A system for spinning a body in certain space probe vehicles and other missile applications capable of accurately stabilizing attitude of spin axis under the influence of load torque impulses is presented; transient response and steady state behavior of the system under various torque loading conditions are analyzed; comparison made between performance obtained with the spinning body control system and similar system for nonspinning body; and the spinning system is capable of performance comparable to that of the nonspinning system.

481. Gausbus, E. V.,
INVESTIGATION OF A SPECIFIC TYPE OF SELF-OSCILLATIONS OF A SPACE VEHICLE (Issledovanie Odnogo Tipa Avtokolebanii Kosmicheskogo Apparata), Iskusstvennye Sputniki Zemli, No. 16, 1963, pp. 57-67, A63-18470 (In Russian).

Included is an analysis of the self-oscillations of a specific type of automatic control system. It is shown that in the presence of perturbations, the period of the self-oscillations is independent of the initial conditions and the magnitude of the sensitivity zone, but that it is completely determined by the perturbations and the magnitude of the impulse. The dependence of power consumption upon the perturbations is a discontinuous function. At a fixed perturbation, the consumption is quantized; the system may assume one of the two possible power levels depending on the initial conditions. The regions of the quantum states of the system are established, and are used to determine the exact value of the power consumption. Also obtained is an exact solution for the period of oscillations. All solutions are given in dimensionless form, and are shown to be valid for any system of the type investigated.

482. Gaylord, R. S. and Keller, W. N.,
ATTITUDE CONTROL SYSTEM USING LOGICALLY CONTROLLED PULSES, ARS Journal, 9 August 1961, ARS Reprint 1921-61, 12 pp.

This paper was presented at the Guidance, Control, and Navigation Conference, 7-9 August 1961, Stanford University.

483. General Electric Co., Johnson City, New York,
RESEARCH AND INVESTIGATION ON SATELLITE ATTITUDE CONTROL, PART II - INVESTIGATION OF SPACE VEHICLE ATTITUDE CONTROL TECHNIQUES, TECHNICAL REPORT, JANUARY 1963-APRIL 1964 by K. C. Nichol, June 1965, AFFDL-TR-64-168, AD-468355, X65-20874, Contract AF-33(657)-7717 (Unclassified).

Not abstracted.

484. Grubin, C.,
A GENERALIZED TWO-IMPULSE SCHEME FOR REORIENTING A SPIN-STABILIZED VEHICLE, ARS Journal, 9 August 1961, ARS Reprint 1922-61, 12 pp.

This paper was presented at the Guidance, Control, and Navigation Conference 7-9 August 1961, at Stanford University. The dynamics of a generalized two-impulse scheme for reorienting the attitude of a symmetric, spin-stabilized vehicle are analyzed. The term generalized derives because the precession angle is not limited to 180 degrees. If all system parameters are ideally impulsive, then the scheme is theoretically perfect. Mechanization of this scheme by means of body-fixed rockets is considered, and the effect of nonideal conditions on system accuracy is examined. These conditions include non-nominal values of spin speed, transverse moment of inertia, and a finite time of rocket firing.

485. Haeussermann, W.,
RECENT ADVANCES IN ATTITUDE CONTROL OF SPACE VEHICLES, ARS Journal, Vol. 32, No. 2, February 1962, pp. 188-195.

This survey covers information published prior to November 1961; attitude control is treated for particular projects from viewpoint of total system integration and as control system for itself, comprising methods and components

for stabilization and optimization toward space vehicle requirements; space vehicles with attitude control systems, passive, and active attitude control; and simulation techniques for attitude control and future development outlook.

486. Haglund, H. H.,
SPACECRAFT CONTROL SYSTEMS, Washington, Spartan Books, Inc., London, Macmillan and Co., Ltd., 1964, pp. 433-448, A65-15557 (International Council of the Aeronautical Sciences, Congress, 3rd, Stockholm, Sweden, 27-31 August 1962, Proceedings, A65-15539 06-34).

Included is a discussion of electronic and electromechanical systems used in spacecraft control systems. The Ranger unmanned lunar probe is described, and its control system is considered. Equipment for the network of Earth-based deep-space instrumentation facilities for communication with space vehicles is briefly reviewed.

487. Haloulakos, V. E.,
ANALYTIC DETERMINATION OF THRUST LEVEL AND IMPULSE REQUIREMENTS FOR SPACECRAFT ON-OFF JET ATTITUDE CONTROL SYSTEMS, American Institute of Aeronautics and Astronautics, Summer Meeting, Los Angeles, California, 17-20 June 1963, Paper 63-237, A63-18881.

Included is a discussion of the fundamental aspects of the spacecraft attitude control problem, in terms of individual maneuvers and overall mission requirements. The required analytical tools are applied to specific cases defined in terms of typical vehicles and missions utilizing all-jet attitude control systems. Specifically, the analysis is applied to determining the over-all impulse and propellant requirements for sample vehicles and missions and also for precisely calculating the required thrust levels. The required thrust level is found to be a function of the propellant used; three distinct thrust levels result when cold gas, hypergolic bipropellant, or monopropellant (using catalytic packs for initiating and sustaining combustion) are compared on the basis of identical impulse requirements. Vehicles weighing 5000, 50,000, and 500,000 pounds are considered, and the thrust and total impulse attitude control requirements for Mars and Venus

transfer missions are evaluated. The control system functions analyzed consist of initial vehicle orientation, occasional reorientation and position stabilization during the coast phase, and the midcourse correction propulsive maneuvers. The results indicate that a single all-jet attitude control system can satisfactorily perform the required tasks, and furthermore that the uniquely defined thrust levels and the associated propellant consumption are low.

488. Haloulakos, V. E., THRUST AND IMPULSE REQUIREMENTS FOR JET ATTITUDE-CONTROL SYSTEMS, Journal of Spacecraft and Rockets, Vol. 1, No. 1, January-February 1964, pp. 84-90.

Analytical approach is used to calculate thrust levels, impulse and propellant requirements for three vehicles in Mars transfer mission; required thrust level is found to be function of propellant used; three distinct thrust levels result when cold gas, hypergolic bipropellant, or monopropellant are compared on basis of identical impulse requirements; control-system maneuvers consist of initial vehicle orientation, occasional reorientation and position stabilization during coast phase, and midcourse-correction propulsive maneuvers; and results indicate that single all-jet control system is satisfactory and that defined thrust levels and propellant consumption are low.

489. Hammell, A. K., FLIGHT CONTROL FOR MANNED SPACECRAFT-GEMINI AND APOLLO-2, IEEE-International Space Electronics Symposium-Record 6-9 October 1964, Paper 7-b-II, 14 pp.

Included is a description of the Apollo command module stabilization and control systems by relating mission requirements to system's functional and mechanization characteristics

490. Heartz, R. A., ELECTRONIC SUPPORT SYSTEM FOR MANNED LUNAR MISSIONS, Aerospace Engineering, Vol. 21, October 1962, pp. 22-29.

Not abstracted.

491. Henderson, B. E.,
A COMPARATIVE STUDY OF CONTROL SYSTEMS FOR THE FINAL DESCENT AND LANDING MANEUVER OF A MANNED LUNAR LANDING VEHICLE, APPENDIX - EQUATIONS OF MOTION, American Institute of Aeronautics and Astronautics, 1963, pp. 88-95, A63-20563 (AIAA Simulation for Aerospace Flight Conference, Columbus, Ohio, 26-28 August 1963).

Included is an examination of the effects of varying degrees of control augmentation on the final phase of a pilot-controlled descent and lunar landing. The investigation was carried out by means of analog simulation which incorporates a small fixed-base simulator cockpit to implement the pilot action. Four control configurations are considered and compared: (1) the zero augmentation system, (2) a rate feedback system, (3) a rate-plus-pseudo-attitude feedback system, and (4) a rate-plus-true-attitude feedback system. It is concluded that the pseudo-attitude feedback system represents the minimum degree of control augmentation necessary to perform the final descent and landing maneuver. Results obtained with the rate-feedback system suggest its possible use as a standby or backup system. Though it does not meet the requirements of precision and minimum effort controllability, it could probably be used to make a successful landing.

492. Hibbard, R. R.,
ATTITUDE STABILIZATION USING FOCUSED RADIATION PRESSURE, ARS Journal, Vol. 31, June 1961, pp. 844-845.

Not abstracted.

493. Holahan, J.,
ATTITUDE CONTROL FOR UNMANNED SPACECRAFT, Space/Aeronautics, Vol. 39, February 1963, pp. 78-86.

Not abstracted.

494. Hughes Aircraft Co., Aerospace Group, Culver City, California, MANUAL ATTITUDE CONTROL SYSTEMS, VOLUME IV - SYSTEM INTERACTION EFFECTS by R. W. Allen, D. K. Bauerschmidt, R. O. Besco, G. G. Depolo, and C. J. Goddard, September 1964, NASA-CR-68087, X66-10807, Contract NASw-620 (Unclassified).

Not abstracted.

495. Huston, R. L.,
GYROSCOPIC STABILIZATION OF SPACE VEHICLES, AIAA Journal, Vol. 1, July 1963, pp. 1694-1696.

Not abstracted.

496. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California,
DERIVED-RATE INCREMENT STABILIZATION ITS APPLICATION TO THE ATTITUDE-CONTROL PROBLEM by J. C. Nicklas and H. C. Vivian, 31 July 1961, JPL-TR-32-69, Contract NASw-6 (Unclassified).

An analysis is presented of a gyro-free nonlinear attitude-control system for a spacecraft. On-off jet actuators are used in the system, and hysteresis and a dead zone are intentionally included. Under certain conditions the feedback signal in the control system is proportional to an angular velocity increment of the system; this is termed single axis of the attitude-control system is given in two parts: one part is concerned with the performance of the system in a limit cycle; the other part discussed the convergence to a limit cycle after a disturbance has occurred.

497. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California,
SPACECRAFT CONTROL SYSTEMS by H. H. Haglund, 1962, X63-15307 (Presented at the 34th Conference of the International Council of the Aeronautical Science, Stockholm, 27-31 August 1962, NASA CR-51017) (Unclassified).

Not abstracted.

498. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California,
SPACE PROGRAMS SUMMARY NO. 37-12, VOLUME II FOR THE PERIOD 1 SEPTEMBER 1961 TO 1 NOVEMBER 1961 (U), 1 December 1961, JPL SPS-37-12, Contract NASw-6 (Confidential).

Research and development activities conducted by the Jet Propulsion Laboratory having specific application to the Lunar program, Planetary-Interplanetary program, Deep Space Instrumentation facility, and the Lunar Advanced Development program are presented.

499. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California,
SPACE VEHICLE ATTITUDE CONTROL AND POWER SYSTEM INTERACTIONS by J. C. Nicklas, X64-17560 (In Pennsylvania University background material for the Study of the National Space Power Program, Volume VI - Miscellaneous Papers, October 1964, 7 pp., X64-17557) (Unclassified).

Not abstracted.

500. Johns-Hopkins University, Silver Springs, Maryland,
EFFECTS OF PASSIVE ATTITUDE CONTROL ON SOLAR POWER SYSTEMS by R. E. Fischell, 5 May 1964, CF-3077, AD-622483, N66-14814, Contract NOw-62-0604-c (Unclassified).

There is a strong relationship between a spacecraft's attitude control system and its capability for generating electrical power from solar cells. The effects of four particularly interesting passive attitude control techniques on the spacecraft's solar power system are discussed. These four techniques are: solar stabilization, spin stabilization, magnetic stabilization, and gravity gradient stabilization.

501. Johnson, R. E.,
ELECTRICALLY SUSPENDED GYROS FOR SPACE APPLICATIONS, American Institute of Aeronautics and Astronautics, Guidance and Control Conference, Cambridge, Massachusetts, 12-14 August 1963, Paper 63-315, A63-20660.

Included is a brief description of the operation and performance characteristics of electrically suspended gyros (ESG). Fundamentally, the ESG is a free gyro with the inertial member, a rotating beryllium sphere, supported by electric field forces in an evacuated envelope containing an orthogonal array of electrodes. A high vacuum is maintained to prevent voltage breakdown between the electrodes and the rotor, and to minimize gas drag which tends to slow the rotor. Advantages of using ESG for spacecraft guidance and control systems include low drift rates, high positional suspension capability, long life, and unlimited freedom. The history of the ESG principle is briefly discussed.

502. Kane, T. R. and Sobala, D.,
NEW METHOD FOR ATTITUDE STABILIZATION, AIAA Journal, Vol. 1, June 1963, pp. 1365-1367.

Not abstracted.

503. Karymov, A. A.,
DETERMINATION OF FORCES AND MOMENTS DUE TO LIGHT PRESSURE ACTING ON A BODY IN MOTION IN COSMIC SPACE, PMM - Journal of Applied Mathematics and Mechanics, Vol. 26, No. 5, March 1963, pp. 1310-1324, A63-15253 (Prikladnaia Matematika i Mekhanika, Vol. 26, September-October 1962, pp. 867-876).

In an attempt to obtain integral characteristics for the determination of the effect of light on the body of a space vehicle, a generalized analysis is included. As examples, calculations are presented of forces and moments due to light pressure acting on the following configurations: an ellipsoid, a right-circular cylinder, a right-circular cone, a hemisphere, a sphere, and a body of revolution with a totally reflecting surface.

504. Kennedy, H. B.,
A GYRO MOMENTUM EXCHANGE DEVICE FOR SPACE VEHICLE ATTITUDE CONTROL, AIAA Journal, Vol. 1, May 1963, pp. 110-118, A63-16993 (Institute of the Aerospace Sciences, Annual-Summer Meeting, Los Angeles, California, 19-22 June 1962, Paper 62-38).

Included is a description of a gyro control device which may be used in attitude control systems requiring momentum exchange devices. It is shown that the use of two single-degree-of-freedom gyros per vehicle axis permits nearly independent control of the three components of vehicle angular rate. The new controller employs only two gyro wheels and three gimbals to effect control of the three components of vehicle angular rate. On the one hand, a moderate degradation of transient response is experienced, owing to increased cross-coupling between vehicle axes; but, on the other hand, significant weight and volume reductions are achieved. It is shown that the gyro controller is an extremely efficient device when its energy requirements are compared with those for a flywheel controller. Digital simulation results are presented to

illustrate the time response of an attitude control system employing the advanced gyro controller.

505. Kennedy, H. B., GYRO MOMENTUM EXCHANGE DEVICE FOR SPACE VEHICLE ATTITUDE CONTROL, AIAA Journal, Vol. 1, No. 5, May 1963, pp. 1110-1118.

This device employs only two gyro wheels and three gimbals to effect control of three components of vehicle angular rate. Moderate degradation of transient response is experienced due to increased cross-coupling between vehicle axes. It is shown that the gyro controller is an efficient device when its energy requirements are compared to those for flywheel controller. Digital simulation results presented illustrate time response of an attitude control system employing an advanced gyro controller.

506. King, C. M., A STABILIZATION AND CONTROL SYSTEM FOR AN INTERPLANETARY SPACE VEHICLE, American Institute of Aeronautics and Astronautics, 1965, pp. 352-360, A65-19533, (AIAA Unmanned Spacecraft Meeting, Los Angeles, California, 1-4 March 1965, AIAA Publication CP-12, A65-19498).

Included is an extension of an earlier design study for the Voyager interplanetary space vehicle. The presentation extends a preliminary design study made for NASA in 1963 for an unmanned space vehicle to explore Mars (or Venus) during the planetary opportunities form 1969 to 1975. A 6000- to 7000-pound vehicle is being planned which is to be placed first in an Earth parking orbit, then later injected into a heliocentric transfer ellipse towards Mars. Tracking, determination of Voyager ephemeris, and the required midcourse corrections are to be done by the DSIF. The Voyager comprises two basic components: an orbiter-bus and a lander vehicle. The necessary stabilization and control system (SCS) is specified, and a detailed comparison is made between the Voyager and the Mariner spacecraft, which has many of the same features. SCS configuration and reaction system tradeoffs are also examined.

507. Kopp, R. E. and Orford, R. J.,
LINEAR REGRESSION APPLIED TO SYSTEM IDENTIFICATION FOR ADAPTIVE CONTROL SYSTEMS, AIAA Journal, Vol. 1, No. 10, October 1963, pp. 2300-2306.

A statistical method for estimating space vehicle parameters as well as vehicle orientation from noise contaminated data is described. It is shown how the method might be applied to an adaptive control system. A second order linear system, representative of the attitude rate control system, illustrates the method.

508. Kurzhals, P. R. and Keckler, C. R.,
SPIN DYNAMICS OF MANNED SPACE STATIONS, 1963, NASA TR R-155.

Included is an analytical study of dynamics of manned rotating space stations under various steady-state and transient excitations, such as docking impacts, attitude system torques, and crew motions. Basic equations of motion for spinning station are developed and expressions simulating applied disturbances introduced. Gyroscopic wobble damper and proportional jet damper are represented and motion of the station under external disturbances are determined with and without effects of these stability systems. Computer results for toroidal stations and effects of variation in moment of inertia distribution are included.

509. Lahde, R. N. and Pawelek, A.,
A VERSATILE SWITCHING LOGIC FOR DISCONTINUOUS ATTITUDE AND MANEUVERING CONTROL SYSTEMS FOR SPACECRAFT, North Hollywood, California, Western Periodicals Co., 1963, pp. 2.2.5-1 to 2.2.5-10, A64-18287 (Annual East Coast Conference on Aerospace and Navigational Electronics, 10th, Baltimore, Maryland, 21-23 October 1963, Proceedings).

Included is a discussion of the design of the switching logic of attitude control systems for space vehicles using reaction jets for the generation of control moments, called "bang-bang" systems. Four different logic systems are compared by analysis and by analog computer tests. One of the systems investigated, called "time-switched integration," has been developed by Lockheed and is shown to be advantageous in certain applications. The advantages are stated to include a remarkable insensitivity of the optimum time response

behavior to slow variations of the level of system acceleration such as are produced by fuel consumption or staging. It is noted that, in this sense, the time switched integration system in some mechanizations may be termed self-adaptive, but achieves this feature with very simple means.

510. Landauer, J. P.,
SIMULATION OF SPACE VEHICLE WITH REACTION JET CONTROL SYSTEM, Instruments and Control Systems, Vol. 37, No. 2, February 1964, pp. 130-134.

A method is presented for simulating attitude control equations of space vehicles for solutions in analog computers.

511. Landon, V. D.,
NUTATIONAL STABILITY OF AN EXISYMMETRIC BODY CONTAINING A ROTOR, Journal of Spacecraft and Rockets, Vol. 1, November-December 1964, pp. 682-684, A65-11371.

Included is a description of an active, but relatively simple, three-axis control technique for space vehicles that is a natural extension of spin stabilization. In this technique, control about the third axis (the spin axis) is achieved by "despinning" a portion of the spinning spacecraft. Instead of the vehicles being constructed as a single body, it is constructed of two bodies constrained to rotate about a common axis. The internal body, if driven by a servo-controlled motor, can be despun and thereafter used as a component stabilized in three axes; in this case, an external reference (such as the Earth or an astronomical body) can be tracked. The nutational stability of the two-body system is considered, and the constraints imposed on the moments of inertia by the requirement for stability are established. OSO 1 (1962 Zeta 1) reportedly utilizes this kind of configuration to achieve three-axis stabilization.

512. Laub, J. H. and McGinness, H. D.,
GAS-FLOATED SPINNING SPHERES, Aerospace Engineering, Vol. 20, No. 12, December 1961, pp. 26-27 and 75-79.

An investigation is extended to the use of a gas-floated spinning sphere for momentum transfer in attitude control of space vehicles, and the use of a rotating free sphere as stable reference in inertial instrumentation. Viscous drag and power requirement of gas floated spheres spinning within a concentric hollow shell and within a multiple pad system are analyzed as

functions of rotational velocity, sphere diameter, spin axis direction, and gas characteristics.

513. Lear Siegler, Inc., Grand Rapids, Michigan, STUDY AND DEVELOPMENT OF A SPACECRAFT DIGITAL STABILIZATION AND CONTROL SYSTEM BIMONTHLY PROGRESS REPORT NO. 2, 17 November 1964, NASA-CR-62854, X65-36516, Contract NASw-1004 (Unclassified).

Not abstracted.

514. LeCompte, G. W. and Bland, J. G., SIMPLY MECHANIZED ATTITUDE CONTROL FOR SPINNING VEHICLES, American Institute of Aeronautics and Astronautics, Guidance and Control Conference, Cambridge, Massachusetts, 12-14 August 1963, Paper 21598, A63-21598.

Included is a description of an attitude-control system in which the two functions required for attitude control of a spinning vehicle (error correction and nutation removal) are accomplished by a single-channel control system. Control torque is applied by a single jet mounted rigidly to the vehicle, producing torque pulses of fixed amplitude and duration when triggered by pulses from a body-mounted passive sensor. The electronics are limited to the sensor amplifier, a fixed-time delay, and a solenoid-valve driver. The valve poppet is the only moving part. Proper orientation depends on positioning the sensor and torquing axis at a unique angular separation determined by the ratio of the spin-axis and normal-axis moments of inertia. Analog simulation results show the performance of the control system in aligning the vehicle spin axis to a point of finite-angular-size reference source. A laboratory satellite simulator has also been operated with this control system.

515. LeCompte, G. W. and Bland, J. G. SIMPLY MECHANIZED ATTITUDE CONTROL FOR SPINNING VEHICLES, Journal of Spacecraft and Rockets, Vol. 1, November-December 1964, pp. 593-598, A65-11135, (American Institute of Aeronautics and Astronautics, Guidance and Control Conference, Cambridge, Massachusetts, 12-14 August 1963, Preprint 63-341).

Not abstracted.

516. Leondes, C. T. (Editor),
MODERN CONTROL SYSTEMS THEORY, New York, New York, McGraw-Hill Book Co., 1965, 486 pp.

CONTENTS

Preface by C. T. Leondes (University of California, Department of Engineering, Los Angeles, California) pp. ix-xiii.

Linear Time-Variable System Synthesis Techniques by A. R. Stubberud (University of California, Department of Engineering, Los Angeles, California) pp. 1-44.

System Synthesis With Random Inputs by C. T. Leondes (University of California, Department of Engineering, Los Angeles, California) and H. C. Hsieh, pp. 45-96.

Functional Analysis and its Applications to Mean-Square Error Problems by R. A. Nesbit (Beckman Instruments, Inc., Santa Monica, California) and H. C. Hsieh, pp. 97-120.

Shaping Filters for Stochastic Processes by E. B. Stear (University of California, Department of Engineering, Los Angeles, California; Lear Siegler, Inc., Research Laboratories, Control and Communication Laboratory, Santa Monica, California) pp. 121-155.

Lyapunov's Direct Method in the Analysis of Nonlinear Control Systems by D. D. Donalson (Hughes Aircraft Co., Functional Design Section, Culver City, California) pp. 156-227.

Review of Adaptive Control System Theories and Techniques by D. D. Donalson (Hughes Aircraft Co., Functional Design Section, Culver City, California) and F. H. Kishi (Space Technology Laboratories, Inc., Redondo Beach, California) pp. 228-284.

An Introduction to the Pontryagin Maximum Principle by by J. S. Meditch (Aerospace Corporation, Los Angeles, California) pp. 285-318.

Minimum Norm Problems and Some Other Control System Optimization Techniques by M. Aoki (University of California, Department of Engineering, Los Angeles, California) pp. 319-334.

Analytical Design Techniques for an Optimal Control Problem by P. R. Schultz (Aerospace Corporation, Systems Research and Planning Division, Injection Guidance Section, Los Angeles, California) pp. 355-372.

Some Elements of Stochastic Approximation Theory and its Application to a Control Problem by P. R. Schultz (Aerospace Corporation, Systems Research and Planning Division, Injection Guidance Section, Los Angeles, California) pp. 373-386.

Analysis and Synthesis of Discrete-Time Systems by G. A. Bekey (University of Southern California, Electrical Engineering Department, Los Angeles, California) pp. 387-430.

Description of the Human Operator in Control Systems by G. A. Bekey (University of Southern California, Electrical Engineering Department, Los Angeles, California) pp. 431-462.

Applications of Modern Methods to Aerospace Vehicle Control Systems by R. A. Nesbit (Beckman Instruments, Inc., Santa Monica, California) pp. 463-382.

Index, pp. 483-486.

517. Lieberman, S. I., BANG-BANG ATTITUDE CONTROL SYSTEM FOR SPACE VEHICLES, Aerospace Engineering, Vol. 21, No. 10, October 1962, pp. 54-55, 64-65, and 68.

Mathematical model of bang-bang reaction jet attitude control system capable of generating high moments in space vehicle is derived on basis of conditional switching techniques. Computer study of the system was accomplished and its actual versus theoretical performance was compared. A study showed that model yields desired attitude change in a minimum amount of time. A parameter study was made to derive magnitude of moments, duty cycle, angular impulse, and dynamic response information.

518. Lincoln Laboratory, Massachusetts Institute of Technology, TIME-OPTIMAL VELOCITY CONTROL OF A SPINNING SPACE BODY by M. Athanassiades, 6 September 1962, LL 22G-8, Contract AF-19(628)-500 (Unclassified).

The controlled system is a body in space with a single axis of symmetry. Gas jets with a limited thrust are used as the controls. It is desired to determine the controls which maintain a given velocity about the axis of symmetry and which drive the velocities about the other two axes to zero

in minimum time. The maximum principle is used to derive the necessary conditions on the controls which are of the "bang-bang" type.

519. Listvin, N.,
ATTITUDE STABILITY OF A SPACESHIP HEADING TO THE MOON (Orientirovanie Korablia, Letiashchego k Lune) Aviatsiia i Kosmonavtika, Vol. 46, May 1964, pp. 80-85, A64-20678 (In Russian).

Included is a brief review of current methods used for attitude stabilization of a space vehicle in the Soviet Union and of the American Vanguard, Explorer, and Pioneer series. The principles of an active stabilization system are examined, and passive stabilization is illustrated on the examples of the solar sail and the gas-diffusion stabilization system.

520. Lopez, A. E., Ratcliff, J. W., and Havill, J. R.,
RESULTS OF STUDIES ON A TWIN-GYRO ATTITUDE CONTROL SYSTEM FOR SPACE VEHICLES, American Institute of Aeronautics and Astronautics, Guidance and Control Conference, Cambridge, Massachusetts, 12-14 August 1963, Paper 63-332, A63-21595.

This article presents a brief review of an investigation on the attitude stabilization of a large space vehicle using twin gyros as torque sources. Two control systems were investigated: an automatic closed-loop system and a pilot-operated system. The automatic system was capable of maintaining attitude stabilization to within one second of arc; the pilot-operated system was capable of attitude stabilization to five seconds of arc. The estimated weight of a twin-gyro control system is compared with that of a reaction control system as a function of the length of time these perform similar attitude-stabilization tasks.

521. Lopez, . E., Ratcliff, J. W., and Havill, J. R.,
RESULTS OF STUDIES ON TWIN-GYRO ATTITUDE-CONTROL SYSTEM FOR SPACE VEHICLES, Journal of Spacecraft and Rockets, Vol. 1, No. 4, July-August 1964, pp. 399-402.

The system consists of a twin-gyro controller for each of three orthogonal axes of space vehicle. With the twin-gyro controller about each axis, cross coupling associated with systems using single gyro about each axis is eliminated which

makes possible the use of large gimbal angles, so that large portion of momentum stored in gyros is available for transfer to vehicle. The control system had rapid response and good damping characteristics. In automatic, closed-loop mode control system was able to maintain attitude of simulator to within one second of arc about all axes.

522. Marino, J.,
SPACE VEHICLE ATTITUDE DYNAMICS DURING VELOCITY CORRECTIONS, American Astronautical Society Journal, 11 August 1960, 13 pp., AAS Preprint 60-79, Contract AF-33(616)-6490.

For missions where post-injection guidance and thrust are used to correct the velocity of space vehicles, performance of the guidance system depends largely upon the attitude-stabilization capability of the flight control system. To perform detailed dynamic analyses of the flight control system, a realistic mathematical model of vehicle attitude dynamics must account for the nonlinear time-varying nature of vehicle characteristics. Previous methods, utilizing small-perturbation assumptions, limit the results to relatively small linear attitude motions that are unsuitable for more detailed studies of control-loop nonlinearities.

523. Marx, M. F.,
DESIGN ASPECTS OF ATTITUDE CONTROL SYSTEMS, IRE Transactions on Automatic Control (USA), Vol. AC-6, No. 1, February 1961, pp. 67-73.

Figures of merit, besides those of performance, are discussed relative to the attitude control system of a vehicle capable of leaving and returning to the atmosphere. In addition to extreme changes in flight condition, these applications are subject to variations in configuration and performance requirements. Traditionally, control optimization has been concerned with minimizing or maximizing a variable system function such as error. Quite often, these error criteria are replaced by other criteria such as invariance and the capacity for adaptability. In fact, during a complete mission, including exit to reentry, it is desirable to utilize variable figures of merit. Examination of the control requirements of a modern returnable space vehicle illustrates how the various figures of merit dictate the design configuration.

In those phases of the mission where self-adaptive control is employed, the figure of merit is usually determined by the particular technique selected. It is further demonstrated how the figure of merit varies with the mission phase as the control actuation configuration changes.

524. Massachusetts Institute of Technology, Instrumentation Laboratory, Cambridge, Massachusetts,
SPACE VEHICLE GUIDANCE INVESTIGATIONS EXPLORATORY DEVELOPMENT PROGRAM, VOLUME II, PART C - CONTROL SYSTEM STUDIES, PART D - INSTRUMENTATION RESEARCH AND DEVELOPMENT, FINAL TECHNICAL REPORT, 10 JANUARY-31 OCTOBER 1964 (U) by W.H. Aldrich, 10 November 1964, R-473, SSD-TR-64-296, AD-355 186, X65-11493, Contract AF-04(695)-290 (Confidential).

Not abstracted.

525. McGraw-Hill Inc., New York, New York,
ANALYSIS OF SOVIET SPACE VEHICLE ATTITUDE CONTROL SYSTEMS (U) by F. G. Ehler, June 1964, MHR-64-42, AD-357 659, N50121, Contract AF-33(657)-12199 (Secret).

Not abstracted.

526. McRuer, D. T. and Stapleford, R. L.,
POWER AND ENERGY REQUIREMENTS FOR A FIXED-AXIS INERTIA WHEEL ATTITUDE CONTROL SYSTEM, ARS Journal, Vol. 31, May 1961, pp. 665-668.

Not abstracted.

527. Melcher, H. J. and Otten, D. D.,
MODULATING BANG-BANG ATTITUDE CONTROLS, Control Engineering, Vol. 12, November 1965, pp. 73-75.

Not abstracted.

528. Minneapolis-Honeywell Regulator Co., Aeronautical Division, Minneapolis, Minnesota,
AN ATTITUDE CONTROL SYSTEM FOR A MANNED LUNAR VEHICLE by D. W. Thompson, 1962, N63-15533 (Unclassified).

A stabilization and control system for a manned lunar flight is discussed. Two possible choices for a stabilizing logic, which would provide the low-rate limit cycles required

during translunar and transearth coast modes, are presented. A solid-state mechanization, functionally similar to the orbit ligic used to stabilize the Mercury capsule, is one possibility. The other is based on previous Honeywell aircraft autopilot controls.

529. Monheit, A. T. and Buckingham, A. G., RECENT ADVANCES IN SPACECRAFT CONTROL, Westinghouse Engineering, Vol. 26, March 1966, pp. 34-40.

Not abstracted.

530. Moskowitz, S., STELLAR ALIGNMENT OF GYROSCOPICALLY STABILIZED PLATFORM DURING FREE FALL, Astronautics and Aeronautics, Vol. 13, 1964, pp. 359-389.

This paper is concerned with operational in-flight alignment of inertial platform meeting operational requirements of rendezvous, orbital transfer, lunar landing, and atmospheric reentry. Requirements of each operation are defined, and theoretical aspects of each given solution investigated. Approaches considered are based upon use of a four-gimbal, all-attitude platform along with feasible combinations of manual sights, automatic celestial tracker, moderate or high accuracy horizon seeker, and space sextant.

531. Mueller, F. K. and Rothe, H. C., SPHERICAL FLYWHEEL FOR ATTITUDE CONTROL, Space/Aeronautics, Vol. 40, December 1963, p. 96.

Not abstracted.

532. National Aeronautics and Space Administration, ANALYTICAL APPROACH TO DESIGN OF AUTOMATIC DISCONTINUOUS CONTROL SYSTEM by L. W. Taylor, Jr. and J. W. Smith, NASA TN D-630, April 1961, 59 pp.

Design of attitude stabilization system for space vehicle experiencing negligible external moments is investigated. A discontinuous control system employing a linear switching function and neutral zone and time delays is studied and equations developed to optimize system's transient and limit-cycle performance. Example systems are included.

533. National Aeronautics and Space Administration, ANALYTICAL METHOD OF APPROXIMATING THE MOTION OF A SPINNING VEHICLE WITH VARIABLE MASS AND INERTIA PROPERTIES ACTED UPON BY SEVERAL DISTURBING PARAMETERS by J. J. Buglia, 1961, NASA TR R-110 (Unclassified).

An analytical method has been developed which approximates the dispersion of a spinning symmetrical body in a vacuum, with time-varying mass and inertia characteristics, under the action of several external disturbances (initial pitching rate, thrust misalignment, and dynamic unbalance). The ratio of the roll inertia to the pitch or yaw inertia is assumed constant. Spin was found to be very effective in reducing the dispersion due to an initial pitch rate or thrust misalignment.

534. National Aeronautics and Space Administration, A SIMPLE SOLAR ORIENTATION CONTROL SYSTEM FOR SPACE VEHICLES by S. Slamirs, September 1962, NASA TN D-1271 (Unclassified).

The control system has been designed and examined on a single-degree-of-freedom air-bearing platform. The response of the system to various initial errors was measured, and phase-plane diagrams of the system performance are presented. Methods of applying control torques are considered, and the application of artificial damping through the proper use of control torques is investigated. The results showed that a simple system may be obtained with the use of reaction jets. The system is capable of pointing accuracies of 18 seconds of arc, and higher accuracies are considered feasible with some modification.

535. National Aeronautics and Space Administration, ROTATIONAL MAGNETODYNAMICS AND STEERING OF SPACE VEHICLES by R. H. Wilson, Jr., September 1961, NASA TN D-566 (Unclassified).

Stable steering of any vehicle requires that there be applied to it restoring or directing torque for turning to required direction, and damping torque by which all rotations and librations may be eliminated by immediate dissipation of energy. Damping torque for steering vehicles in outer space is demonstrated by studies of magnetic rotational damping of Vanguard Satellites I and II; suggestions made.

536. National Aeronautics and Space Administration, TECHNIQUE FOR SYNTHESIS OF CONSTANT LINEAR DYNAMICAL SYSTEMS WITH BANG-BANG CONTROLLER by J. H. Suddath and T. M. Carney, August 1964, NASA TR R-200, (Unclassified).

Synthesis technique employing linear switching logic with time-dependent gains was investigated. With the assumption that variable gains would eliminate endpoints, conditions for asymptotic stability were obtained from considerations of Liapunov functions. A technique was successfully applied in analog computer simulation of idealized attitude control system for spinning space vehicles.

537. National Aeronautics and Space Administration, THEORY OF ARTIFICIAL STABILIZATION OF MISSILES AND SPACE VEHICLES WITH EXPOSITION OF FOUR CONTROL PRINCIPLES by R. F. Hoelker, June 1961, NASA TN D-555 (Unclassified).

This theory is derived by a more rigorous method than was done in the past. Path reaction models are classified by setting them into relation to two solutions, drift minimum and load minimum modes. Other control modes are developed, concerned with local lateral acceleration along missile axis; these are maximum comfort control modes and methods of controlling center or hinge point of motion resulting from combination of rotary with path motion.

538. National Aeronautics and Space Administration, USE OF INERTIA SPHERE TO DAMP ANGULAR MOTIONS OF SPINNING SPACE VEHICLES by J. H. Suddath, 1962, NASA TR R-137, (Unclassified).

General moment equations for spin-stabilized vehicle with inertia-reaction angular rate damper were considered, and it was noted that simplification would result if damper had spherical inertia distribution. A control system incorporating such damper was postulated. Resulting equations were linearized, and conditions for stability obtained from analysis of cubic characteristic equation; two numerical examples.

539. National Aeronautics and Space Administration, Ames Research Center, Moffett Field, California,
A TWIN-GYRO ATTITUDE CONTROL SYSTEM FOR SPACE VEHICLES by J. R. Havill and J. W. Ratcliff, August 1964, NASA TN D-2419, N64-27121 (Unclassified).

This report describes the twin-gyro concept and the study of a three-axis attitude control system. Results of experimental data obtained from laboratory tests that used physical components are presented. A twin-gyro controller consists of two counterrotating gyro elements arranged so that control torque is always directed about a single axis independent of gyro gimbal angle. This feature allows the use of large gimbal angles so that a major portion of the momentum stored in the gyros can be transferred to the vehicle without introducing cross-coupling torques. The twin-gyro attitude control system uses three twin-gyro controllers to provide torques about three orthogonal vehicle axes. To study the control system experimentally, it was mounted on a space vehicle simulator. The vehicle simulator had large values of inertia and was supported on a low-friction spherical air bearing. The results of the experimental study, which are given in the report, show that a twin-gyro control system can stabilize a vehicle to precise attitudes (within one-arc second) with good dynamic response. The system transfer function is derived, and a comparison of the measured response with the calculated response shows that the system performance can be predicted analytically. General theoretical equations of motion, derived for a single-degree-of-freedom gyro, a twin-gyro controller, and a three-axis twin-gyro attitude control system, are included.

540. National Aeronautics and Space Administration, Ames Research Center, Moffett Field, California,
RESULTS OF SIMULATOR STUDIES ON THE ATTITUDE CONTROL OF A SPACE VEHICLE TO A FEW SECONDS OF ARC by A. E. Lopez and J. W. Ratcliff, July 1963, pp. 113-121, X64-12313 (In NASA, Washington, Guidance, Control, and Communication, X64-12306) (Unclassified).

Not abstracted.

541. National Aeronautics and Space Administration, Langley Research Center, Langley Station, Virginia,
FLIGHT INVESTIGATION OF A SOLAR ORIENTATION CONTROL SYSTEM FOR SPACECRAFT by A. Fontana, J. D. Maynard, M. L. Brumfield, and O. J. Parker, January 1964, NASA TM X-944, N64-12712 (Unclassified).

A three-axis solar orientation control system for the spacecraft has been designed and built and has been tested both on the ground and in spaceflight to determine its capabilities. The system is simple; it is relatively compact; it has no moving parts other than a relay, solenoid valves, and a single rate gyro; and it is rugged enough to withstand severe environments, both during launch and in space. Silicon solar cells are used in the sensing elements for the pitch- and yaw-control axes, and the controlling torques for pitch, yaw, and roll are generated by simple cold gas, on-off reaction jets. In general, the flight test results confirmed the predicted capability of the system to efficiently orient any specified axis of a spacecraft toward the center of the solar disk with a limit cycle amplitude of no more than ±3 minutes of arc.

542. National Aeronautics and Space Administration, Langley Research Center, Langley Station, Virginia,
LUNAR SATELLITE PERTURBATIONS by R. H. Tolson, X63-14583 (Intercenter Technological Conference on Control, Guidance, and Navigation Research for Manned Lunar Missions, Ames Research Center, 24-25 July 1962, pp. 344-346, X63-14557) (Unclassified).

Not abstracted.

543. National Aeronautics and Space Administration, Langley Research Center, Langley Station, Virginia,
MINIGUIDE - A SIMPLIFIED ATTITUDE CONTROL FOR SPIN-STABILIZED VEHICLES by H. J. E. Reid, Jr. and A. D. Garner, NASA RP-230, N64-25601 (Journal of Spacecraft and Rockets, Vol. 1, No. 3, May-June 1964, pp. 342-344, Presented at the AIAA Summer Meeting, Los Angeles, California, 17-20 June 1963) (Unclassified).

A description is given of the simple control theory for a pitch-attitude and a vertical-attitude control scheme. The vertical control uses a horizon detecting telescope with a field of view several degrees wide. This telescope is set at an angle with respect to the spin axis which (when the axis is vertical and the vehicle is at the correct altitude) allows the field of view to sweep around the edge of the apparent Earth disk. In this condition, the portion of the field of view occupied by Earth remains the same throughout the revolution of the vehicle. If the spin axis of the vehicle is not vertical, the portion of the field of view occupied by Earth will change as the vehicle spins. The horizontal version of the pitch control uses two body-fixed horizon detectors with narrow fields of view mounted on opposite sides of the vehicle spin axis. A successful flight test of the pitch-control scheme is described, and two applications are considered.

544. National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama,
PRELIMINARY STABILITY ANALYSIS OF SATURN I BLOCK II VEHICLES by R. S. Ryan, 7 March 1963, MSFC MTP-AERO-63-18 (Unclassified).

This report presents the results of various vibration and stability analyses conducted for the Saturn Block II space vehicle. Particular emphasis is placed upon stiffness requirements for the Apollo capsule that will produce an acceptable control system design.

545. National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama,
THE INFLUENCE OF CONTROL SENSORS ON THE STABILITY OF SPACE VEHICLES by M. H. Rheinfurth, 22 August 1961, MSFC MTP-AERO-61-65 (Unclassified).

Not abstracted.

546. National Aeronautics and Space Administration, Washington, D.C.,
SPACE VEHICLES ELECTRONICS AND CONTROL RESEARCH, PROGRAM REVIEW (U) by R. C. Seamans, Jr., 9 March 1963, TM-X-50817, X63-15827 (Confidential R/D).

Not abstracted.

547. New, N. C.,
SPACECRAFT ATTITUDE CONTROL FOR EXTENDED MISSIONS, VOLUME I (Ph.D. Thesis) May 1963, 148 pp. NASA CR-53556, TE-1, N64-18302, NASA NsG-254-62.

An interplanetary mission of a 400-day duration is adopted as a general guide for the problem, but most of the equations and comparisions are presented in parametric form. Extended missions imply that a momentum-exchange attitude control system be used to minimize ejection of fuel mass, and the thesis primarily considers systems of this type. The equations of motion are derived for a spacecraft equipped with 18 different control systems. The control system chosen to best satisfy the design requirements is a system consisting of four gyro-type controllers arranged in two pairs, with each pair operating back-to-back to minimize control cross-coupling torques. One pair of controllers provides roll torques, and all four controllers contribute yaw torques. The stability and control analysis considers operation of the spacecraft in three modes (zero input mode, rate control mode, and position control mode).

548. New, N. C.,
SPACECRAFT ATTITUDE CONTROL FOR EXTENDED MISSIONS, VOLUME II, (Ph.D. Thesis) May 1963, 196 pp. NASA CR-53555, TE-1, N64-18303, NASA NsG-254-62.

Not abstracted.

549. Nicklas, J. C. and Vivian, H. C., DERIVED-RATE INCREMENT STABILIZATION: ITS APPLICATION TO THE ATTITUDE CONTROL PROBLEM, ASME Transactions, Series D, Vol. 84, March 1962, pp. 54-60.

Not abstracted.

550. Ormsby, R. D. and Smith, M. C., CAPABILITIES AND LIMITATIONS OF REACTION SPHERES FOR ATTITUDE CONTROL, ARS Journal, Vol. 31, No. 6, June 1961, pp. 808-812.

This article presents important characteristics of electrically suspended reaction sphere for space vehicle attitude control and data presented on capabilities and limitations of concept, factors to be considered, and data from experimental and analytical investigation.

551. Patapoff, H., APPLICATION OF THE RATE DIAGRAM TECHNIQUE TO THE ANALYSIS AND DESIGN OF SPACE VEHICLE ON-OFF ATTITUDE CONTROL SYSTEMS, ARS Journal, 9 August 1961, 16 pp., ARS Reprint 1924-61.

This paper was presented at the Guidance, Control, and Navigation Conference 7-9 August 1961, at Stanford University. Preliminary signle axis analysis and design of a space vehicle control system, consisting of a torque producing device and a dead-band within which there are no externally or internally applied torques, can be accomplished quite effectively by a simple graphical technique termed the "rate diagram" method. Two characteristics of typical space vehicle attitude control problems, which make this method effective, are the undamped rigid body motion of the vehicle and the associated low angular rates. The interpretation of a rate diagram for analysis and design purposes is discussed, and a detailed treatment of an example space vehicle control system problem to exemplify this technique is included.

552. Ponomarev, V. M.,
CONTROL THEORY OF MOTION OF SPACE VEHICLES
(Teoriia Upravleniia Dvizheniem Kosmicheskikh Apparatov),
Moscow, Izdatel'stvo "Nauka," 1965, 456 pp., A65-33032
(In Russian).

This book develops a general control theory for space vehicles and general principles for designing space control systems. The introduction to the book contains a historical review of the development of space control systems and a brief statement of the problem of synthesizing an optimum control system. Chapter I examines the general characteristics of space-vehicle motion, the equations of motion of a space vehicle, special cases of space-vehicle motion, and methods of devising control action and obtaining information on vehicle motion. Chapter II derives basic criteria for optimum control and introduces the concepts of programmed control and control law. Chapter III reviews the principal mathematical methods used in the synthesis of optimum control, describes the general features of optimum control programs for space vehicles, and develops an approximate method for the solution of systems of linear inhomogeneous differential equations with variable coefficients. Chapters IV through VII deal with methods of synthesizing optimum control programs for various types of vehicle motion (atmospheric reentries, soft landing from a lunar orbit, vertical landing, rendezvous, docking, and similar maneuvers), and give examples of continuous and sample-data programs. Chapter VIII treats random (external and internal) perturbation effects. Chapter IX develops a method for synthesizing continuous and sampled-data optimum linear control laws. The book should be of interest to scientists and engineers working in the field of automatic control.

553. Reid, H. J. E., Jr. and Garner, A. D.,
MINIGUIDE - A SIMPLIFIED ATTITUDE CONTROL FOR SPIN-STABILIZED VEHICLES, Journal of Spacecraft and Rockets, Vol. 1, May-June 1964, pp. 342-344, A64-18619, (American Institute of Aeronautics and Astronautics, Summer Meeting, Los Angeles, California, 17-20 June 1963, Paper 63-210).

Not abstracted.

554. Roberson, R. E.,
RADIATION PRESSURE TORQUES FROM SPATIAL VARIATIONS IN SURFACE PROPERTIES, Journal of Spacecraft and Rockets, Vol. 2, July-August 1965, pp. 605-607, A65-28861.

This article discusses the development of the probable density function for torque components on spacecraft arising from solar radiation pressure. Even when the surface is symmetrical, or at least balanced, with respect to the vehicle center of mass, a torque can exist because of differential reflectivity of surface elements and variations in the direction of the surface normal, both caused by local surface irregularities. The physical model used in the mathematical analysis of the probable density function is an array of solar cells whose properties might reasonably be assumed constant but are statistically different from those of neighboring cells. The effects of surface variations, expected torque value, and the stochastic model and correlation functions are mathematically expressed. The equations for the special case of normal incidence on a plane area are derived. It is shown that, generally speaking, the torques from surface vairations are inferior to those caused by gross asymmetries or shadowing of the surface.

555. Rodden, J. J. and Montague, L. D.,
DESIGN OF AN ATTITUDE CONTROL SYSTEM WITH MAGNETOMETER SENSORS, AIAA Journal, Vol. 1, June 1963, pp. 1422-1424, A63-17981.

This article discusses a presentation of the design of an attitude-control system using magnetometers for attitude intelligence. The system is unique in that it is designed to capture a vehicle from any initial unknown attitude and motion to establish a specific known attitude with respect to the Earth. A schematic diagram of the attitude control system is given. The system which uses a three-axis contactor or on-off servo is designed to perform the reacquisition function by aligning the vehicle longitudinal axis parallel to the local magnetic-field vector which is well defined with respect to the Earth at any given location.

556. Rogers, M. and Shapiro, G., CLOSED-LOOP FLIP-FLOP CONTROL SYSTEMS, Journal of Aerospace Sciences, Vol. 27, November 1960, pp. 841-853.

Not abstracted.

557. Royal Aircraft Establishment, Great Britain, THE ACQUISITION OF SUN POINTING ATTITUDE BY SPACE VEHICLES WITHOUT THE USE OF RATE GYROSCOPES by J. K. Abbott, May 1965, RAE TR 65097 (Unclassified).

Not abstracted.

558. Schaefer, R. A., PULSE RATIO MODULATION FOR ATTITUDE CONTROL, Space/Aeronautics, Vol. 39, May 1963, pp. 90-93, A63-18329.

Included is a description of a new nonlinear pulse ratio modulation (PRM) technique which, compared with previously used linear methods, meets the performance requirements of spacecraft attitude-control systems and is simple to put into hardware form. The PRM technique, which provides inherent damping that is most effective at low rates, is shown to possess the following features: (1) dynamic range, (2) pulse frequency, (3) pulse width, (4) maximum demand, and (5) predictable performance. The equations that define the characteristics of the PRM control system are logically derived from the response capabilities of the reaction jets, considered together with available electronic circuit techniques. Responses of linear and nonlinear PRM systems are compared and graphically represented.

559. Schmieder, L., Schubert, H., and Zimmermann, K., ATTITUDE CONTROL OF SPACE VEHICLES BY MEANS OF UNBALANCE MASS (Lageregelung Von Raumfahrzeugen Mittels Schwungmassen), Zeitschrift für Flugwissenschaften, Vol. 13, October 1965, pp. 357-372, A66-11984 (Wissenschaftliche Gesellschaft für Luft - und Raumfahrt, and Deutsche Gesellschaft für Raketentechnik und Raumfahrt, Jahrestagung, Berlin, West Germany, 14-18 September 1964, Paper) (In German).

Not abstracted.

560. Seacord, C. L.,
FLIGHT CONTROL FOR MANNED SPACECRAFT, Space/Aeronautics, Vol. 40, November 1963, pp. 72-80, A64-10691.

This article presents a review of the basic parameters affecting the design of flight stabilization and control systems for manned spacecraft. Considered are vehicle type, mission duration, mission objective, vehicle weight, and the method of thermal control of equipment. The flight control systems for the X-20 delta-winged orbital glider and the Apollo spacecraft and proposed methods of flight control for orbital stations are discussed.

561. Shearin, J. G. and Kurzhals, P. R.,
STABILITY AND CONTROL OF MANNED ROTATING SPACE STATIONS, American Astronautical Society - Advances in Astronautical Sciences, Vol. 13, 1963, pp. 61-74.

Stations used in orbital assembly and launch operations require rotation to maintain station attitude and stability, and to provide artificial gravity for crew. Primary flywheel wobble damper and backup pulse jet damping and orientation system are considered and control logic and experimental simulation. Efficiency of systems in eliminating station wobbling motions resulting from crew transfer, docking impacts, and other external torques is analyzed by integrating equations of motion on IBM 7090 computer. The results and test data are obtained.

562. Space Technology Laboratories, Inc.,
STUDY OF PILOT CONTROL OF THE LUNAR EXCURSION MODULE DURING HOVER AND LANDING by J. C. Fox, April 1963, STL 9350.7-6 (Unclassified).

Not abstracted.

563. Stafford, R. L.,
PRELIMINARY CONSIDERATIONS FOR ATTITUDE CONTROL OF SPACE VEHICLES, American Astronautical Society Journal, 11 August 1960, AAS Preprint 60-78,21 pp.

A space vehicle moving through the solar system will be subjected to numerous torques tending to change its attitude. Although these disturbances are small, substantial attitude perturbations will result if they are not properly controlled. The disturbing torques that are considered herein result from

atmospheric, solar, micrometeoric, gravitational, magnetic, and internal movement effects. The nature of each effect is described and a comparison is made between the magnitudes of the various torques for manned and unmanned vehicles operating in cislunar and interplanetary space.

564. Stanford University, California,
BASIC STUDIES IN SPACE VEHICLE ATTITUDE CONTROL, FOURTH SEMIANNUAL STATUS REPORT by I. Flügge-Lotz and R. H. Cannon, Jr., June 1963, NASA CR-50602, X63-14196, Grant NsG-133-61 (Unclassified).

Not abstracted.

565. Stanford University, California,
BASIC STUDIES IN SPACE VEHICLE ATTITUDE CONTROL, FIFTH SEMIANNUAL STATUS REPORT, MARCH 1962-SEPTEMBER 1963 by R. H. Cannon, Jr., and I. Flügge-Lotz, December 1963, NASA CR-55347, X64-11528, Grant NsG-133-61 (Unclassified).

Not abstracted.

566. Stanford University, Department of Aeronautics and Astronautics, California,
BASIC STUDIES IN SPACE VEHICLE ATTITUDE CONTROL, NINTH SEMIANNUAL STATUS REPORT by I. Flügge-Lotz and R. H. Cannon, Jr., December 1965, NASA CR-69657, N66-15977, Grant NsG-133-61 (Unclassified).

The studies of the design of control systems which include a human operator and attitude control of a flexible, spinning, toroidal manned space station are reviewed. Also, optimum and suboptimal control of the pitch motion of a satellite in elliptic orbit, the complete attitude control problem for an Earth satellite in elliptic orbit, the validity of linearization in attitudes control, random disturbances in control problems, computation of approximately optimal control, rigorous error bounds on position and velocity in satellite orbit theories, and solar perturbation of Mars orbiters are discussed.

567. Stanford University, Department of Aeronautics and Astronautics, California,
BASIC STUDIES IN SPACE VEHICLE ATTITUDE CONTROL, SEVENTH SEMIANNUAL STATUS REPORT by R. H. Cannon, Jr., and I. Flügge-Lotz, December 1964, NASA CR-60910, X65-35783, Grant NsG-133-61 (Unclassified).

Not abstracted.

568. Standord University, California,
VECTOR RETICLE, CONTROL ACTION DISPLAY IN MANUAL CONTROL OF SPACE VEHICLE ATTITUDE by R. H. Cannon, Jr., and W. G. Eppler, Jr., November 1964, AD-616 185, N50121, Grant NsG-133-61 (Unclassified).

Two concepts, the vector reticle and control action display, are submitted as effective means for making manual three-axis attitude control quicker and more efficient while reducing substantially the concentration required of the pilot. A system design is submitted in which the two concepts are combined in a control action reticle and in which the pilot has direct control of the jet valves. (The entire system may be mechanical.) The system is controlled to a visual reference or to an instrument attitude reference. Malfunction of the system cannot interfere with normal manual control. The vector reticle presents all auxiliary information in a single three-part geometric vector superimposed on the window (rather than on three separate dials, for example), thus reducing the number of quantities to be monitored from three to one. Control action display gives the pilot instantaneous and exclusive control of the reticle, thus removing the need for two mental integrations and greatly reducing the concentration required for tracking. Results are presented of three-axis (fixed-base) simulation studies of the proposed system and of other systems for comparison.

569. Stear, E. B.,
CRITICAL LOOK AT VEHICLE CONTROL TECHNIQUES, <u>Astronautics and Aerospace Engineering,</u> Vol. 1, August 1963, pp. 80-83.

Not abstracted.

570. Stuart, W. H.,
SATELLITE ATTITUDE STABILIZATION BY MEANS OF FLY-WHEELS, Aerospace Engineering, Vol. 20, September 1961, pp. 10-11.

Not abstracted.

571. Sullivan, G. and Peters, W.,
LOGIC BANG-BANG SYSTEM FOR EXO-ATMOSPHERIC ATTITUDE CONTROL, IEEE National Aerospace Electronics Conference, Proceedings, 1963, pp. 202-205.

This article presents the theoretical analysis of a simple bang-bang system to provide torques for momentum attitude control system in which reaction jets are used to change vehicle orientation by torquing momentum vector. The use of jets of simple on-off control type results in reduced electronic complexity. Although torquing of momentum vector will result in desired precession, it will also induce undesired nutation of vehicle about momentum vector. Since simple on-off torquing does not provide damping, extreme care must be taken to prevent nutation from becoming excessive.

572. Sung, C. B. and Schaffer, D. J.,
DYNAMIC CONTROL SYSTEMS REQUIRE DYNAMIC DESIGNERS, Society of Automotive Engineers Journal, Vol. 71, March 1963, pp. 36-44.

Not abstracted.

573. Taplin, L. B. and Teitelbaum, R. B.,
STATE-OF-ART OF SPACE VEHICLE ATTITUDE CONTROL, ISA Proceedings, Preprint 33.4.62 for Meeting 15-18 October 1962, 11 pp.

Control and stabilization methods are discussed including use of disturbance forces such as gravity gradient, dynamical methods, mass expulsion, and momentum exchange devices. A simplified control system is analyzed showing natural frequency and damping expressions for controlled vehicles.

574. Tempelman, W. H.,
NEW INVESTIGATIONS IN FIELD OF ERROR PROPAGATION, Astronautics and Aeronautics, Vol. 13, 1964, pp 727-754.

Two extensions are made to field of perturbation analysis; first is derivation of how transition matrix for cutoff condition of time leads to transition matrix for any cutoff condition expressible as linear function of differential change in initial and final states of system; second extension shows that selection of coordinate system affects accuracy of predicted terminal error. Special coordinate system is selected that maintains high accuracy for periodic dynamical systems.

575. Thomas, W. T. and Reiter, G. S.,
MOTION OF AN ASYMMETRIC SPINNING BODY WITH INTERNAL DISSIPATION, AIAA Journal, Vol. 1, June 1963, pp. 1429-1430.

Not abstracted.

576. Tierney, T. E. and Curran, R. J.,
DEVELOPMENT OF ELECTROSTATIC SUSPENSION REACTION SPHERE, SAE Paper 865D for Meeting 27-30 April 1964, 6 pp.

This article presents the development by Bendix Corporation of reaction sphere serving as controller in space vehicle attitude control system. Requirements included stall torque of 0.02 ft-lb about each axis, momentum storage capability of 0.5 ft-lb-sec about each axis, capability of being suspended in one-g field, 90 percent probability with 90 percent confidence level of functioning for three years in space environment, and mechanical and electric design details. Reaction sphere design supports five-inch diameter spherical rotor by means of four electrostatic force vectors. Three orthogonal stator windings produce stall torque of 0.02 ft-lb and maximum angular momentum of 0.5 ft-lb-sec.

577. Tschauner, J.,
THE STABILIZATION OF SPACE MISSILES, Regalungstechnik (Germany), Vol. 13, No. 10, October 1965, pp. 484-487 (in German).

The optimum stabilization of the position of space missiles in relation to their trajectory is discussed. This is of particular importance where the position to be stabilized does not possess a natural stability.

578. Unterberger, R.,
METHODS FOR ATTITUDE STABILIZATION AND CONTROL OF A SPACECRAFT (Methoden der Lagestabilisierung und Steuerung Eines Raumkörpers) Raumfahrtforschung, Vol. 9, July-September 1965, pp. 132-137, A65-30322 (In German).

Included is a description of various techniques for stabilizing the attitude of satellites and space probes. The simplest form, the passive mode, utilizes the gradient of the Earth's gravitational field with respect to a given satellite axis. Stabilization by rotation is intermediate between passive and active stabilization. Details are given as to how the mechanism which controls the gas nozzles for imparting such spin is itself oriented. More complex systems, in which the object does not rotate and control is achieved by small thrusts from gas nozzles, are described. They can be divided into four classes consisting of: (1) startracking sensor systems, (2) magnetometric sensor systems, (3) inertial guidance systems (motor-driven spinning masses), and (4) rotating fluid systems based on the torque caused by the rotation of a fluid (Hg) around an axis.

579. Vaeth, J. E.,
FLYWHEEL CONTROL OF SPACE VEHICLES, IRE Transactions on Automatic Control (USA), Vol. AC-5, No. 3, August 1960, pp. 247-259.

An analytical study of flywheel autopilots for attitude control of space vehicles is described, and the results of a three-axis analogue-computer programme are presented. The objectives of this study were to determine the requirements, capabilities, and limitations of flywheel autopilots as functions of desired accuracy and speed of response, disturbing moments, differential gravity restoring torques, component uncertainties, and vehicle initial attitude and attitude rate errors. The stability and accuracy degradations that resulted from not compensating for gyroscopic cross-coupling torques are summarized. Design tools are presented for synthesizing a three-axis autopilot in accordance with specified design criteria of size, power, accuracy, response rate, and error disturbances.

580. Vickers, Inc., Research and Development Department, Troy, Michigan,
FEASIBILITY STUDY OF AN ALL-FLUID DIGITAL CONTROL SYSTEM, August 1965, NASA CR-66067, X66-13865, Contract NAS1-4729 (Unclassified).

Not abstracted.

581. Virginia Polytechnic Institute, Blacksburg, Virginia,
THE ROLE OF SIMULATION IN SPACE TECHNOLOGY-PROCEEDINGS OF THE CONFERENCE, 21 August 1964, CONF-640806, Pt C (Unclassified).

Not abstracted.

582. Wells, R. C.,
GYROSCOPIC LOW-POWER ATTITUDE CONTROL - GLOPAC, American Institute of Aeronautics and Astronautics, Summer Meeting, Los Angeles, California 17-20 June 1963, Paper 63-212, 13 pp., A63-18430, Contract AF-33(616)-7870.

Included is a description of a gyroscopic attitude-control system which uses four single-axis power gyros mounted in a tetrahedral arrangement. After the system is described, the derivation of the basic gyro equations is presented. The characteristic operation of both the open- and closed-loop attitude control using four gyros is illustrated by a recent analog study of a vehicle similar to the Voyager. Described is a three-axis control weighing 300 pounds, built and installed on a simulated vehicle to prove the feasibility of the four-gyro system. Briefly discussed are the bind-up, saturation, reliability, and area of utility of the four-gyro control.

583. White, J. B.,
METEORIC EFFECTS ON ATTITUDE CONTROL OF SPACE VEHICLES, ARS Journal, Vol. 32, January 1962, pp. 75-78.

Not abstracted.

584. Whittaker Corporation, Controls and Guidance Division, Chatsworth, California,
SINGLE PLANE CONTROL SYSTEM FOR THE NIKE-JAVELIN, FINAL REPORT by R. T. Martin, May 1965, TR-65-43, AD-467 032, Contract AF-08(635)-3771 (Unclassified).

The roll-stabilized, single-plane attitude control unit developed for the air proving ground center is described. This report contains a summary of the ground testing program and a simulation computer program for the attitude control. The attitude control unit was developed for the Nike-Javelin space probe to be used in project Trump.

585. Widrow, B.,
RATE OF ADAPTATION IN CONTROL SYSTEMS, ARS Journal, Vol. 32, No. 9, September 1962, pp. 1378-1385.

This article discusses the principles of feedback control used by adaptation mechanism. A reference is made to pattern recognizing filters composed of adaptive Adaline neurons. Electric circuit element memistor (resistor with memory), devised to facilitate realization of Adaline neuron, is compact rugged electrochemical element whose resistance can be controlled reversibly by electroplating. The experiences of neuron are stored in resistance values in simple and directly usable form.

586. Woestemeyer, F. B.,
GENERAL CONSIDERATIONS IN THE SELECTION OF ATTITUDE CONTROL SYSTEMS, Society of Automotive Engineers, 1965, pp. 245-265, A66-10681, (Aerospace Vehicle Flight Control Conference, Los Angeles, California, 13-15 July 1965, Proceedings, A66-10661).

This article discribes the examination of the constraints affecting the choice of the basic attitude control system to be used and of tradeoffs in the selection, sizing, and mode of operation of the components with which it may be implemented. To the great benefit of the spacecraft designer, there is now a broad spectrum of guidance and control techniques and components from which to choose. Thus, in the integration of the overall vehicle, he has considerable freedom in selecting not only the preferred components but also the most advantageous modes of system operation. Guidance and control functions are usually interrelated, and the optimum choice may have a major

effect on the vehicle configuration. The primary characteristics, both of the techniques and the hardware, are classified according to various criteria. The spectrum of vehicles is also classified according to characteristic requirements. Examples are drawn from existing spacecraft. Other systems now awaiting suitable application, or under development, are discussed and characteristic advantages are defined.

587. Abzug, M. J., Martin, L. W., and Ohgi, F. T.,
TIME OPTIMAL ATTITUDE CONTROL SYSTEM DESIGNED TO OVERCOME CERTAIN SENSOR IMPERFECTIONS, Progress in Astronautics and Aeronautics, Vol. 13, 1964, pp. 231-259.

Attitude control is obtained through use of two modes of operation, "time-optimal" or convergence mode and "impulse-optimal" or limit cycle mode, choice of which is dependent upon magnitude of system error; convergence to the limit cycle is shown for the case without external torques; convergence time is about one-tenth that of the comparable attitude control system (Dahl's Pulse Modulated System).

588. Arguello, R. J. and Webber, A. L.,
CONTINGENCY ANALYSIS - THE SELECTION OF ALTERNATE OR BACK-UP GUIDANCE AND NAVIGATION MODES FOR A MANNED SPACEFLIGHT, Institute of Electrical and Electronics Engineers, Space Electronics and Telemetry Group, 1964, pp. 5-a-1 to 5-a-15, A65-11461 (International Space Electronics Symposium, Las Vegas, Nevada, 6-9 October 1964, Record).

This paper is a presentation of a technique for the selection of the appropriate navigation and guidance modes from a set of admissible modes for a manned spaceflight. An attempt is made to develop a methodology which would further the judgement ability of the astronaut in making a correct choice of available modes of operation. A solution of the network routing problem is presented. Useful algorithms for high-speed machine computation are devised to select the guidance and navigation modes for a manned deep-space mission. The algorithms provide a technique for the efficient handling of cost data derived from dynamic simulations of various phases of the mission.

589. Army Ballistics Missile Agency, Huntsville, Alabama,
THE OPTIMIZATION OF INTERPLANETARY TRAJECTORIES by R. E. Burns, 3 December 1959, DSP-TN-20-59 (Unclassified).

The problem of the optimal transfer of a rocket vehicle in a vacuum by impulsive thrusts is treated from two viewpoints. In Section I, the theory is developed from simple

differentiations of velocity vectors under the assumption of an inverse square field. Section II is an application of Section I to the theory developed by Derek F. Lawden in the paper "Minimal Rocket Trajectories".

590. Athans, M., et al,
OPTIMAL CONTROL OF SELF-ADJOINT SYSTEMS, IEEE Transactions on Applications and Industry, Vol. 83, May 1964, pp. 161-166.

Not abstracted.

591. Athans, M., Falb, P. L., and Lacoss, R. T.,
TIME-OPTIMAL VELOCITY CONTROL OF SPINNING SPACE BODY, IEEE - Transactions on Applications and Industry, Vol. 82, No. 67, July 1963, pp. 206-214.

Problem of minimum time angular velocity control of spinning space body, with single axis of symmetry, is examined. Control thrusts are assumed bounded; two-axis, gimballed, and single-axis controls are considered. Optimal controls law is derived for each method; comparison of response times indicates that gimballed control is best. Manned space station with requirement of constant artificial gravity is illustrative of type of problem that is analyzed. (Paper 63-98).

592. Author Unknown,
JET-CONTROLLING GYRO PROMISES TO SAVE SPACE-CRAFT'S FUEL, Machine Design, Vol. 37, 27 May 1965, p. 10.

Not abstracted.

593. Beckwith, R. E.,
APPROXIMATE DISTRIBUTION OF NEARLY CIRCULAR ORBITS, AIAA Journal, Vol. 2, No. 2, May 1964, pp. 913-916.

Theory of errors is employed to assess precision of guidance system designed to place payload in prescribed circular orbit. Subject to certain hypotheses about parameters of vehicle's propulsion and guidance systems at burnout, form of distribution of square of orbital eccentricity is obtained,

and several approximations to it are presented. It is indicated how knowledge of this distribution may be used to estimate probability of mission success, and how this quantity may be used to study various questions of interest to the system planner.

594. Beletskii, V. V. and Egorov, V. A., INTERPLANETARY FLIGHTS BY MEANS OF ENGINES OF CONSTANT POWER (Mezhplanetnye Polety S Dvigateliami Postoiannoi Moshchnosti), Kosmicheskie Issledovaniia, Vol. 2, May-June 1964, pp. 360-391, A64-21107, (In Russian).

This paper is a discussion of the problem of interplanetary flights (to Mars, Venus, and Jupiter) by a vehicle powered by an ion or plasma engine on the assumption of constant jet thrust. The analysis makes use of a method based on the linearization of the equations of a problem with respect to a certain suitably chosen reference trajectory. The simplicity and accuracy of the method are demonstrated in application to: (1) a flight with optimum control of thrust acceleration, and (2) flight with a constant thrust-acceleration vector for a single change in its direction.

595. Boeing Co., Seattle, Washington, AN INTRODUCTION TO THE LINEARIZED THEORY OF SPACE CRAFT GUIDANCE EVALUATION by A. R. Duste, 1964, D2-90596, N65-25250 (Unclassified).

The theory considered is that necessary to evaluate guidance requirements for a vehicle which is launched into a trajectory by a booster whose operation contains errors, which has its actual trajectory determined from measuring instruments which have operating errors, and which are controlled by a system which also has operating errors. Linearization of the theory is achieved by assuming that the actual trajectory of the vehicle deviates only slightly from a known nominal trajectory. The state of the vehicle is described in terms of six small quantities called the deviation in state variables and represented by components of the vector $\delta \underset{\sim}{X}$. Control is taken to be an impulsive velocity change $\underset{\sim}{V}g$ calculated from the deviated state at time of control by the linear relation $\underset{\sim}{V}g = (G, H)\delta\underset{\sim}{X}$. Guidance matrices G and H are determined by requiring satisfaction of specified terminal conditions with constraints on $\underset{\sim}{V}g$ so that its magnitude

be a minimum. Linear theory of trajectory determination from various types of navigation measurements containing random and bias errors is developed for single- and multiple-stage estimation procedures. Statistical techniques for trajectory determination procedures are described. Random and bias error sources are considered. Random error sources are assumed Gaussian and bias errors, small. The results give first order approximation of the probable full requirements for control and the probability that the objectives of a mission are achieved.

596. Bollermann, W.,
REPRESENTATION OF THE PATH AND VELOCITY COORDINATES OF AN INTERPLANETARY FLIGHT BY MEANS OF THE GENERALIZED KEPLER APPROXIMATION AND CORRECTIONS IN THE ITERATION METHOD (Eine Darstellung für Bahn- und Geschwindigkeitskoordinaten in der Interplanetarischen Raumfahrt Durch Eine Verallgemeinerte Kepler-Näherung und Korrekturen im Iterationsverfahren), Wissenschaftliche Gesellschaft für Luft- und Raumfahrt, and Deutsche Gesellschaft fur Raketentechnik und Raumfahrtforschung, Jahrestagung, Berlin, West Germany, 14-18 September 1964, Paper, A65-21027 (In German).

Generalized approximate solution of the n-body problem of celestial mechanics which takes account of the Kepler motion of all involved celestial bodies and permits a calculation of the effects of interferences on the initially prescribed flight parameters is discussed. Apart from determining the path and velocity coordinates of an interplanetary flight, the solution extends to such additional forces as thrust and radiation pressure.

597. Breakwell, J. V. and Rauch, H. E.,
OPTIMUM GUIDANCE FOR A LOW THRUST INTERPLANETARY VEHICLE, American Institute of Aeronautics and Astronautics, 1965, pp. 256-269, A66-10026, Contract NAS1-3777 (AIAA/ION Guidance and Control Conference, Minneapolis, Minnesota, 16-18 August 1965, A66-10001).

Analysis of the problem of the optimum guidance in two dimensions of a constant-acceleration low-thrust vehicle spiraling away from and in toward a planet is covered in this paper. The optimization problem - to reach specified energy

with minimum mass expenditure (minimum time, in this case) - is solved using the calculus of variations; the guidance problem is solved by using a neighboring optimum control scheme which generates a linear feedback control law. In both the near-planet and far-planet regions, approximate analytic solutions are derived for the optimum and neighboring optimum trajectories. For the inward spiral, the optimum turn-on time is derived as a function of the radial distance and the angular momentum. Numerical and, in some cases, analytic results are presented for both the original optimum trajectory and the guidance coefficients in the feedback control law.

598. Breakwell, J. V. and Tung, F., MINIMUM EFFORT CONTROL OF SEVERAL TERMINAL COMPONENTS, Society for Industrial and Applied Mathematics Journal, Vol. 2, No. 3, 1964, pp. 295-316.

Stochastic control for minimizing total average velocity correction with several prescribed terminal variances in presence of random injection and measurement errors is considered. It is shown that optimum linear corrective strategy is, in general, discontinuous and consists of initial period of no control, followed by period of continuous control and period of no control with possible impulse at end. Equations are derived from which variable feedback gain and various time intervals can be computed, applicable to interplanetary navigation.

599. Breakwell, J. V., Tung, F., and Smith, R. R., APPLICATION OF THE CONTINUOUS AND DISCRETE STRATEGIES OF MINIMUM EFFORT THEORY TO INTERPLANETARY GUIDANCE, AIAA Journal, Vol. 3, May 1965, pp. 907-912, A65-25318, Contract NAS1-3777 (American Institute of Aeronautics and Astronautics, and Institute of Navigation, Astrodynamics Guidance and Control Conference, Los Angeles, California, 24-26 August 1964, Paper 64-664).

Not abstracted.

600. Carney, R. and Conover, T., DIGITAL ATTITUDE CONTROL SYSTEM, IEEE Transactions on Aerospace and Navigational Electronics, Vol. ANE-10, March 1963, pp. 45-49, A63-19936.

This paper is a description of a simple "minimum-fuel," digital attitude-control system requiring no rate gyros. The system is applicable to practically any type of orbiting space vehicle. An inertial guidance computer furnishes a quantized attitude angle to the control system. With this attitude information and a measure of time, the control computer accurately computes the vehicle's average rate. A novel switching zone arrangement in the phase plane results in decisions controlling on-off reaction jets that adjust the vehicle's attitude. Jet selection and duration of jet operation are determined as functions of the vehicle's angular position and average rate in relation to the switching zones in the phase plane. The system operates so that computed rates are very accurate when accurate rates are required and less accurate when accuracy is not important. The end result is a system that converges to a low-rate limit cycle while consuming near-minimum fuel. The parameters controlling the switching logic are prestored memory constants which are electronically loadable and changeable. This flexibility makes the system compatible with a wide variety of payloads and missions.

601. Case Institute of Technology, Cleveland, Ohio, A MIDCOURSE GUIDANCE PROCEDURE FOR ELECTRICALLY PROPELLED INTERPLANETARY SPACECRAFT by A. L. Friedlander, 1963, N65-10873 (Unclassified).

Linear perturbation techniques and the method of adjoint functions are employed to derive the fundamental guidance equations in the form of recursive-state transition relations. An optimal guidance policy, in the sense of minimizing a quadratic performance index involving the control forces and subject to the desired terminal conditions, is formulated. A celestial navigation scheme with measurements taken at discrete intervals is postulated as the primary mode of state determination. Utilizing a priori statistical information concerning the random disturbances and measurement errors, an optimal prediction and filtering procedure is formulated that yields the "best" up-to-date estimate of the state. Statistical expressions are derived for use in evaluating the integrated guidance theory. Numerical results of guidance performance are presented for a representative Earth-Mars transfer assuming circular, coplanar orbits.

602. Conrad, D. A.,
MINIMUM FUEL CLOSED-LOOP TRANSLATION, AIAA Journal, Vol. 3, May 1965, pp. 952-954.

Not abstracted.

603. Craig, A. J. and Flügge-Lotz, I.,
INVESTIGATION OF OPTIMAL CONTROL WITH A MINIMUM-FUEL CONSUMPTION CRITERION FOR A FOURTH-ORDER PLANT WITH TWO CONTROL INPUTS: SYNTHESIS OF AN EFFICIENT SUBOPTIMAL CONTROL, ASME Transactions, Series D, Vol. 87, March 1965, pp. 39-57.

Not abstracted.

604. Daubert, H. C., Jr.,
A SPACECRAFT DIGITAL CONTROLLER, Society of Automotive Engineers, 1965, pp. 370-376, A66-10689, Contract NASw-1004 (Aerospace Vehicle Flight Control Conference, Los Angeles, California, 13-15 July 1965, Proceedings, A66-10661).

This paper is a description of a study and experimental evaluation program performed to apply digital techniques to the problem of spacecraft stabilization and control. Because of the capability of extended accuracy, digital systems are indicated for guidance and control of spacecraft. Furthermore, by implementing these systems with integrated microelectronic components, substantial improvement in reliability can be expected. Of major consideration in the program were the selection of appropriate mathematical techniques for system analysis and the development of suitable fabrication methods for hardware implementation. A discrete state model of a spacecraft reaction wheel and jet attitude control system was developed and computer simulations were performed. An electronic control unit for this system was designed, constructed with semiconductor integrated microelectronics, and tested on an air bearing simulator. The mathematical model of the system is presented and the experimental performance is compared with the computer simulation of the system.

605. Denham, W. F. and Speyer, J. L., OPTIMAL MEASUREMENT AND VELOCITY CORRECTION PROGRAMS FOR MIDCOURSE GUIDANCE, AIAA Journal, Vol. 2, May 1964, pp. 968-969.

Not abstracted.

606. Denham, W. F. and Speyer, J. L., OPTIMAL MEASUREMENT AND VELOCITY CORRECTION PROGRAMS FOR MIDCOURSE GUIDANCE, AIAA Summer Meeting, Los Angeles, California, 17-20 June 1963, Paper 63-222, A63-18840, Contract NAS9-498.

Consideration of the estimation and control of the perturbations in the preplanned midcourse portion of a space mission trajectory. The problem investigated is the optimization of the measurement program and/or the feedback control gain program. The performance index is a scalar function of the expected values of quadratic forms in the perturbations and/or in the errors in the estimates of perturbations. Necessary conditions for the desired extremal solutions and a steepest-ascent computation procedure for obtaining approximate optimizations are presented. A numerical example is given in which the sequence of stars and near-body horizons to be sighted for the midcourse phase of a lunar mission is selected to minimize the terminal point uncertainty in position (or a weighted average of position and velocity uncertainties). The numerical scheme is shown to converge to essentially the same result, starting with various nominal measurement programs. The minimum rms uncertainty in position at the terminal point is 10 percent less than the value obtained using the scheme suggested by Battin.

607. Dunlap and Associates, Inc., Santa Monica, California, APPLICATIONS OF THE PREDICTOR DISPLAYS TO THE CONTROL OF SPACE VEHICLES by C. R. Kelley, M. B. Mitchell, and P. H. Strudwick, 30 April 1964, NASA CR-65155, X66-11723, Contract NASw-619 (Unclassified).

The application of predictor displays to problems of manual control of spacecrafts is considered. System considerations, including the nature and types of thrusters, maneuvering accuracy requirements, and planned means for meeting these requirements are discussed. Seven control

modes, ranging from the simplest manual mode through fully automatic control, are described. Controls and displays in use or projected, including those employed in Mercury, Gemini, and Apollo are included. Several predictor displays were developed in keeping with the state-of-the-art of spacecraft systems and the maneuvering requirements of projected spacecraft missions. Practical considerations of predictor display use aboard spacecraft, including expense, weight, volume, and reliability, are reviewed. Manual remote control of a roving lunar surface vehicle, rendezvous predictor displays, and spacecraft attitude predictor displays are also considered.

608. Ehricke, K. A., MISSION ANALYSIS OF FAST MANNED FLIGHTS TO VENUS AND MARS, North Hollywood, California, Western Periodicals Co., 1963, pp. 470-546, A63-23872 (American Astronautical Society, Annual Meeting, 9th, Los Angeles, California, 15-17 January 1963, Advances in the Astronautical Sciences, Vol. 13).

This paper is a study of several interplanetary mission profiles for manned flights to Mars and Venus, including a flyby mission, a capture mission, and a landing mission. Mission objectives are defined, with particular attention to the ultimate goal of landing and surface exploration of the target planet. Interplanetary mission maps are constructed, providing the basis for a first-order definition of suitable mission windows (combinations of Earth-departure window, capture period, and target planet departure window, as well as the associated transfer periods). Criteria for mission window selection are presented. Methods of reducing vehicle weight and overall mission energy are discussed, as are navigation requirements. Several different mission modes available for fast manned interplanetary reconnaissance missions and for direct flights are examined.

609. Fimple, W. R., OPTIMUM MIDCOURSE PLANE CHANGES FOR BALLISTIC INTERPLANETARY TRAJECTORIES, APPENDIX A - ANALYTICAL DETERMINATION OF MINIMUM ΔV CONDITIONS FOR THE PROBE, APPENDIX B - DETERMINATION OF MINIMUM ΔV CONDITIONS FOR THE SATELLITE, AIAA Journal, Vol. 1, February 1963, pp. 430-434, A63-13744.

Analysis of midcourse plane changes for ballistic interplanetary trajectories designed to eliminate certain recurring periods of high-velocity requirements that are associated with interplanetary trajectories in the absence of plane changes. The midcourse plane change is optimized so as to minimize the required total velocity increment for both planetary probe missions and planetary satellite missions. Illustrating an application, curves of trip time and velocity requirement versus launch date are presented for Earth-Mars trajectories during the 1964-1965 time period. The velocity requirements for trajectories with midcourse plane changes are compared with the requirements for corresponding single-impulse trajectories that lie in a single plane.

610. Flügge-Lotz, I. and Craig, A., CHOICE OF TIME FOR ZEROING A DISTURBANCE IN A MINIMUM-FUEL CONSUMPTION CONTROL PROBLEM, ASME Transactions, Series D, Vol. 87, March 1965, pp. 29-38.

Not abstracted.

611. Flügge-Lotz, L. and Marbach, H., OPTIMAL CONTROL OF SOME ATTITUDE CONTROL SYSTEMS FOR DIFFERENT PERFORMANCE CRITERIA, ASME Transactions, Series D, Vol. 85, January 1963, pp. 165-176.

Not abstracted.

612. Foy, W. H., Jr.,
FUEL MINIMIZATION IN FLIGHT VEHICLE ATTITUDE CONTROL, IEEE Transactions on Automatic Control, Vol. AC-8, No. 2, April 1963, pp. 84-88.

Design of single-axis rigid-body flight vehicle attitude controller to minimize control fuel consumption is formulated in framework of system optimization theory. Performance measure which consists of integral-square position and rate errors plus control fuel expended, with arbitrary relative weighting factors, is employed. Pontryagin's Maximum Principle is invoked to show that controller which minimizes this measure is of bang-off-bang type.

613. Foy, W. H., Jr. and Lefferts, E. J.,
OPTIMAL ATTITUDE CONTROL OF SPACE VEHICLES, IRE East Coast Conference on Aerospace and Navigational Electronics, Technical Paper 4.1.2, 22-24 October 1962.

A mathematical model of the space vehicle is formulated for a wide choice of performance criteria, optimal attitude control is shown by Pontryagin's Maximum Principle to be so-called bang-bang operation.

614. Friedland, B.,
OPTIMUM SPACE GUIDANCE AND CONTROL, General Precision Aerospace, Technical News Bulletin, Vol. 6, Second Quarter, 1963, pp. 10-21, A63-19282.

Presentation of a new approach to the mathematical formulation of the problem of controlling a space vehicle with regard to its three distinctive aspects; trajectory optimization, guidance, and computation of a new optimum course when the original course is untenable. Equations of motion are derived taking into account in-flight, integral, and terminal constraints. To solve the problem, the fundamental equations of optimum control are also considered. As an example, the problem of single-axis attitude control is solved.

615. Friedlander, A. L.,
OPTIMAL PRE-FLIGHT AND ADAPTIVE POLICIES FOR PLANETARY APPROACH PHASE GUIDANCE, National Aerospace Electronics Conference, 17th, Dayton, Ohio, 10-12 May 1965, Proceedings, A65-29228 18-09, A65-29241 (Dayton, Institute of Electrical and Electronics Engineers, Dayton Section, 1965, pp. 108-119).

This paper is a description of basic concepts and techniques for solving problems of deep-space trajectory corrective maneuvers. Specifically, the problem treated concerns the impulsive correction of target error along a perturbed ballistic trajectory in the near vicinity of the target-body intercept. The guidance objective is to minimize the mean value of the total corrective velocity increment subject to the constraint that the final rms miss distance be within a specified range. This objective is met by determining the proper sequence of spacing of velocity corrections. Two types of guidance policies for selecting the time instants to perform the maneuvers are considered. The preflight policy involves the selection of fixed points along the trajectory at which corrections are to be made. The adaptive in-flight policy is one in which the sequence of correction times is determined by the conditions of actual flight rather than being fixed before launch.

616. Friedman, A. L., Dushman, A., and Gelb, A.,
OPTIMIZATION OF SAMPLING LONG-TERM INERTIAL NAVIGATION SYSTEMS, IEEE Transactions on Aerospace Navigational Electronics, Vol. ANE-11, No. 3, September 1964, pp. 142-172.

A general theory of optimum linear estimation is considered in relation to the problem of reconstructing a non-stationary random signal sampled at arbitrary times and in the presence of a sampling noise. The resulting optimum filter predictor takes the form of a growing memory digital compensator. Presentation of the theory is tutorial, and a contrast to recursive estimation is discussed. Application is made to the use of external discrete position information in a long-term inertial navigator. A comparison between the optimized system and a reference (nonoptimum) system is presented. Consideration is also given to truncation effects and the very important matter of the effect of poorly estimated

problem statistics on performance of the optimized system. Digital computer simulation studies are presented.

617. General Dynamics/Convair, San Diego, California, FINAL GUIDANCE EQUATIONS AND PERFORMANCE ANALYSIS FOR CENTAUR AC-5 by R. E. Roberts, 15 February 1965, GD/A-BTD-64-204, NASA CR-64245, X65-37480, Contract NAS3-3232 (Unclassified).

Not abstracted.

618. General Precision, Inc., Little Falls, New Jersey, ADVANCED FEEDBACK CONTROL TECHNIQUES FOR AEROSPACE VEHICLES by B. Friedland, 15 March 1963, GPI RR 63-RC-1 (Unclassified).

The use of the qualitative results of optimum control theory as a guide to rational design of suboptimum control systems is a subject for research. A program for such research is presented in this document.

619. General Precision, Inc., Research Center, Little Falls, New Jersey, CONTROL AND GUIDANCE THEORY RESEARCH AT THE AEROSPACE RESEARCH CENTER, 2 November 1964, ETO-717, N65-16443.

This study was conducted in an effort to develop practical tools which can be used by engineers for the design of guidance and control systems for aerospace vehicles. Research based primarily on mathematical principles already developed was done on the following programs: Study of Trajectory Optimization Techniques, Trajectory Optimization Computer Program, Extensions to the Kalman Filter Theory, Techniques of Feedback Guidance and Control, Optimum Interception, Optimum Rendezvous, Control of an Aerodynamically Unstable Booster, Space Vehicle Attitude Control, Models for Aerospace Vehicles, and Digital Computer Sinulation Programs.

620. Graham, R. G.,
STEEPEST-ASCENT SOLUTION OF MULTIPLE-ARC OPTIMIZATION PROBLEMS, AIAA Journal, Vol. 3, January 1965, pp. 154-155.

Not abstracted.

621. Grumman Aircraft Engineering Corporation, Bethpage, New York,
A REFERENCE SOLUTION FOR LOW-THRUST TRAJECTORIES by G. Pinkham, N63-18691 (National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama, Studies in the Fields of Space Flight and Guidance Theory, 26 June 1962, pp. 44-51, N63-18688) (Unclassified).

This report presents an analytical solution to the trajectory equations for a low-thrust rocket when the thrust is tangential and varies nearly inversely with the square of the radius from the central body. The variation in the thrust magnitude has been so chosen that the solution possesses as many arbitrary constants as the order of the system of differential equations governing the motion. Thus an Encke or variation-of-parameters analysis of neighboring trajectories is practicable.

622. Grumman Aircraft Engineering Corporation, Bethpage, New York,
AN APPLICATION OF A SUCCESSIVE APPROXIMATION SCHEME TO OPTIMIZING VERY LOW-THRUST TRAJECTORIES by G. Pinkham, N63-16804 (National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama, Progress Report No. 3 on Studies in the Fields of Space Flight and Guidance Theory 15 June - 20 December 1962, 6 February 1963, pp. 57-62, N63-16801) (Unclassified).

This report describes an application of a successive approximation scheme for optimization of low-thrust trajectories involving many revolutions about a central body. The equations-of-motion, written in terms of orbital parameters rather than position and velocity components, are analyzed, and a convenient thrust formula is derived. This formula, together with the variation-of-parameters method of trajectory computation, has been programmed for the IBM 7090.

623. Grumman Aircraft Engineering Corporation, Bethpage, New York,
THREE-DIMENSIONAL LOW-THRUST INTERPLANETARY TRAJECTORY OPTIMIZATION by H. K. Hinz and H. G. Moyer, N63-18690 (National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama, Studies in the Fields of Space Flight and Guidance Theory, 26 June 1962, pp. 5-43, N63-18688) (Unclassified).

A successive approximation technique has been used to compute three-dimensional optimal low-thrust interplanetary trajectories. For this purpose, two IBM-7090 computer programs have been developed - one for constant thrust applications and the other for variable thrust problems. The computer programs generate and store the planetary ephemeris, and automatically optimize the trajectories for missions such as rendezvous and intercept. The "penalty function" technique is used to handle constraints on the position and velocity components and the fuel weight at the terminal point. Optimum low-thrust Earth-to-Mars rendezvous and intercept trajectories have been numerically computed for two synodic periods from January 1965 to July 1969. Initial results, when compared with previous coplanar studies, indicate that there are no highly significant differences between two- and three-dimensional optimum low-thrust interplanetary trajectories. This tentative conclusion, based upon limited results, should not be generally accepted until additional numerical studies are carried out. The result appears to be associated with the small (1.85 degree) inclination of Mars' orbit to the ecliptic.

624. Gurley, J. G.,
OPTIMAL-THRUST TRAJECTORIES IN ARBITRARY GRAVITATIONAL FIELD, Society for Industrial and Applied Mathematics Journal, Vol. 2, No. 3, 1964, pp. 423-432.

Variation of usual calculus of variations technique is discussed. Results include usual first-order criteria for optimality; singular arcs, on which magnitude of solution of adjacent differential equation is continuously equal to critical value, are shown to exist in all except simplest gravitational fields, and in some cases may form part of optimal trajectory; and calculation of unique value of thrust required to sustain singular arc, and test for optimality of such arcs are described.

625. Hall, B. A., Dietrich, R. G., and Tiernan, K. E., A MINIMUM FUEL VERTICAL TOUCHDOWN LUNAR LANDING GUIDANCE TECHNIQUE, APPENDIX A - ANALYSIS OF TERMINAL POSITION OF MPN CONTROL LAW, APPENDIX B - ADJOINT ANALYSIS, American Institute of Aeronautics and Astronautics, Guidance and Control Conference, Cambridge, Massachusetts, 12-14 August 1963, Paper 63-345, A63-20668, Contract NASw-469.

This paper is a description of an automatic, easily instrumented guidance technique, which is suitable for accomplishing a soft, pinpoint, vertical lunar landing with a nearly minimum fuel expenditure. The use of this technique, called modified proportional navigation guidance (MPN) results in a total incremental velocity penalty of about 100 feet per second compared to the total velocity increment required by the minimum fuel landing trajectory. The sensitivity of the technique to random and bias sensor errors and to dynamic lags in the sensor outputs and vehicle engine response is examined. It is shown that the critical sensor errors are range and range rate. Additional fuel requirements resulting from initial condition deviations are determined.

626. Hayes International Corporation, Birmingham, Alabama, ORBITAL ELEMENT EQUATIONS FOR OPTIMUM LOW THRUST TRAJECTORIES by H. Passmore, III, 6 February 1963, pp. 63-96, N63-16801, N63-16805 (National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama, Progress Report No. 3 on Studies in the Fields of Space Flight and Guidance Theory, 15 June - 20 December 1962).

The three-dimensional optimum-trajectory relations developed by Messrs J. G. Cox and W. A. Shaw are transformed into a form that appears more amenable to low-thrust-trajectory calculations. Orbital-element coordinates, commonly used in celestial mechanics, are employed due to their slow variation in low-thrust applications. Combinations of these elements and a generalized eccentric anomaly are utilized in arranging the resulting equations in a form which does not contain circular singularities.

627. Heartz, R. A. and Jones, T. H., HYBRID SIMULATION OF SPACE VEHICLE GUIDANCE SYSTEMS, Institute of Electrical and Electronics Engineers, Space Electronics and Telemetry Group, 1964, pp. 5-c-1 to 5-c-12, A65-11463 (International Space Electronics Symposium, Las Vegas, Nevada, 6-9 October 1964, Record).

Application of analog and digital computer simulations to the design, reliability assessment, checkout, and training functions of space-vehicle guidance systems is discussed. The guidance requirements for a lunar landing system are discussed. The system is reduced to a mathematical representation for simulation and is diagrammed. The simulation allows studying of guidance problems associated with missile launch, rendezvous, reentry, aerodynamic energy management, lunar landing, and other space maneuvering. Results of the simulations prove to be of value in the analysis of radar look angles as a function of steering dynamics, effects of guidance constants on system accuracy, methods of combining radio and inertial navigational data, failures and off-nominal system performance, and reentry-trajectory limit conditions.

628. Horn, H. J., APPLICATION OF AN ITERATIVE GUIDANCE MODE TO A LUNAR LANDING (Anwendung Eines Iterativen Lenkverfahren auf Eine Mondlandung), Raumfahrtforschung, Vol. 8, April-June 1964, pp. 49-54, A64-18538 (In German).

Development of closed solutions to simplified trajectory optimization problems for minimum propellant consumption, such as a homogeneous gravitational field,is discussed. These solutions, which provide approximations to real conditions, can be used as steering equations if applied repetitively. The approximations improve gradually, and the end conditions can be reached with any desired degree of accuracy. This iterative guidance mode is applied to a lunar landing. Calculated propellant losses are negligible. Real time computation was achieved with a small, medium-speed computer, which proves the feasibility of the iterative guidance mode for an on-board computation.

629. Horn, H. J.,
APPLICATION OF AN "ITERATIVE GUIDANCE MODE" TO A LUNAR LANDING (Deutsche Gesellschaft für Raketentechnik und Raumfahrt), European Space Flight Symposium, 3rd, Stuttgart, Germany, 21-24 May 1963, Paper 1504(63), A63-19489.

Presentation of a method of optimizing space-vehicle trajectories (minimizing expenditure of propellant) by using the calculus of variations to determine a new optimum trajectory from an instantaneous state to the end point of the flight is discussed. By using analytical solutions of simplified problems as iteratively improving approximate solutions for the real problem, computation effort is reduced to such an extent that real-time calculation of the optimum trajectories with on-board components becomes possible. This iterative mode is applied to a theoretical lunar landing problem, and is found to give solutions close to the time optimum.

630. Hu, S. S. and Thompson, M. L.,
A DIRECT AND ANALYTICAL SOLUTION FOR SPACE FLIGHT GUIDANCE FUNCTIONS, American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 3rd, New York, New York, 24-26 January 1966, Paper 66-94, A66-17093, Contract NASw-1165.

The primary purpose of this study was to establish a new technique for obtaining, by analytical methods, polynomial-type guidance functions for optimal space flight. These guidance functions should allow the conversion of current values of the state variables and specified mission parameters into values for the optimum steering directions and cutoff time; they should continually furnish them egardless of previous disturbances to the vehicle's tra ctory. To date, an operating analytical solution has not been achieved and the necessary guidance functions are obtained either by near optimum approximations or statistical methods which are applicable to simplified or restricted flight paths. To illustrate this analytical approach, an example in the form of optimum ascent to circular orbit is worked out in detail and results are shown to agree quite well with those obtained by conventional numerical methods through calculus of variations.

631. Jazwinski, A. H.,
QUADRATIC AND HIGHER-ORDER FEEDBACK GAINS FOR CONTROL OF NONLINEAR SYSTEMS, AIAA Journal, Vol. 3, No. 5, May 1965, pp. 925-935.

The problem of controlling nonlinear systems optimally in the presence of deterministic disturbances is treated, in particular, optimal feedback control in the vicinity of optimal nominal trajectory; the control law is to preserve optimality of nominal path and provide terminal control to the nominal end point defined by hard constraints on functions of the terminal state; method of obtaining approximations of any order to such nonlinear optimal feedback control law is presented; and close-form expressions for linear and quadratic gains for simple intercept problem and their simulations are presented.

632. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California,
OPTIMUM INTERPLANETARY RENDEZVOUS TRAJECTORIES WITH POWER-LIMITED VEHICLES by W. G. Melbourne and C. G. Sauer, Jr., 15 October 1962, JPL-TR-32-226, Revision 1, NASA CR-53030, N64-13404, Contract NAS7-100 (Unclassified).

The optimum-thrust equations for both variable and constant thrust are presented. These thrust programs are used to generate rendezvous trajectories from the Earth to Mars for various flight times and launch dates during the years 1968-1971. The manner in which the propulsion requirements vary with flight time and launch date are considered, and a comparison of vehicle performance using the variable- and constant-thrust programs is presented. The optimization of the propulsion system parameters is discussed, and the existence of optimum launch dates is interpreted in terms of certain transversality conditions derivable from the calculus of variations. A brief comparison of the advanced propulsion vehicle and the ballistic vehicle propulsion requirements is made for Earth-Mars rendezvous trajectories.

633. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California,
THE STATISTICAL ANALYSIS OF SPACE GUIDANCE SYSTEMS by A. R. Noton, 15 June 1960, JPL TM-33-15, Contract NASw-6 (Unclassified).

In analyzing the errors of guidance systems, JPL experience has indicated that the treatment of injection-errors as independent random variables may sometimes be a poor approximation. Statistical calculations of dispersions at the destination, or of the magnitude of a midcourse maneuver, must take into account cross-correlations between injection errors. The appropriate theory is presented in this memorandum.

634. Kelley, H. J.,
SECOND VARIATION TEST FOR SINGULAR EXTREMALS, AIAA Journal, Vol. 2, No. 8, August 1964, pp. 1380-1382.

The second variation for the Mayer problem is examined with reference to singular test extremals and evaluated for the case of special variation in the control variable; by means of limiting process, necessary conditions for minimum is obtained from requirement of positive semidefiniteness of second variation; some applications of test to singular extremals arising in flight mechanics problems are presented, such as simplified version of optimal midcourse guidance problem by C. T. Striebel and J. V. Breakwell.

635. Kelley, H. K.,
GUIDANCE THEORY AND EXTREMAL FIELDS, IRE Transactions on Automatic Control, Vol. AC-7, No. 5, October 1962, pp. 75-82.

Various aspects of trajectory optimization are discussed, and guidance concept using optimal flight path properties is developed; analysis, based on Jacobi's accessory minimum problem for second variation, is equivalent to field of extremals in vicinity of predetermined extremal chosen as nominal trajectory.

636. Krasovskiy, A. A.,
THERMAL NOISE OF MEASURING DEVICES AND LIMITING ACCURACY SELF-CONTAINED GUIDANCE OF A SPACE SHIP (Foreign title not available), Translated into English from Russian by Air Force Systems Command, Foreign Technology Division, Wright-Patterson Air Force Base, Ohio, FTD-MT-65-130, 25 May 1965, AD-615 861, N65-29584.

The limiting effects of thermal noise on the accuracy of inertial measuring systems and dispersion of trajectories of spaceships with automatic guidance systems was investigated. Presented is a theoretical analysis of open inertial systems. Comparative data on the limiting accuracy of inertial systems of angular orientation and the limiting accuracy of open navigational inertial systems are included. It was demonstrated that the limiting accuracy of an inertial system, which is determined by taking into account the thermal changes of orientation of the accelerometer and the disturbing accelerations is essentially lower than the limiting accuracy during ideal orientation. It was further found that errors of the inertial system are almost completely triggered by the automatic guidance circuits and cause corresponding dispersion of spaceship trajectories.

637. Ladd, H. O., Jr. and Friedland, B.,
MINIMUM FUEL CONTROL OF SECOND-ORDER LINEAR PROCESS WITH CONSTRAINT ON TIME-TO-RUN, Joint Automatic Control Conference, 19-21 June 1963, pp. 241-246.

It is shown that minimum-fuel operation of process with amplitude limitation and specified time-to-run is "bang-off-bang"; explicit expressions for surfaces in state-space, on which switching takes place, are given for processes having real characteristic roots, and for areas of impulses in terms of current state as limiting forms of switching surfaces for amplitude limited control; and results are applicable to aerospace vehicle attitude control.

638. Lee, C. T. and Desoer, C. A.,
FUEL OPTIMAL CONTROL FOR PULSE-AMPLITUDE-MODULATED TIME-INVARIANT SAMPLED-DATA SYSTEM, Journal of Electronics and Control, Vol. 15, No. 4, October 1963, pp. 363-381.

The problem, which is an idealization of the attitude control problem of space vehicles, is solved for unbounded and partly for bounded control systems. The sequence of control vectors that brings state to origin in N sampling periods, or less, with least consumption of fuel is presented.

639. Lieberman, S. I. and Margosian, Z.,
A CLASS OF TIME-OPTIMAL VELOCITY CONTROL LAWS FOR A SPINNING SPACE VEHICLE, IEEE Transactions on Automatic Control, Vol. AC-9, July 1964, pp. 286 and 287, A64-23673 (Unclassified).

This paper is an examination of the problem of minimum-time angular velocity control about the two nonspinning axes of a cylindrical body spinning about its transverse axis. Due to the non-normality of the equations of motion, the optimum control law derived for this problem is not unique in two of the four switching regions of the phase plane. For those two regions, several optimum bang-bang control laws are determined, and a control error function valid for all initial conditions is described. Given the initial pitch and yaw body rates, the control system will drive these rates to zero in minimum time.

640. No entry.

641. Lockheed Missiles and Space Co., Palo Alto, California, APPLICATION OF THE CONTINUOUS AND DISCRETE STRATEGIES OF THE MINIMUM EFFORT THEORY TO INTERPLANETARY GUIDANCE by J. V. Breakwell, F. Tung, and R. R. Smith, 1964, N64-27651, Contract NAS1-3777 (Presented at the AIAA/ION Astrodynamics Guidance and Control Conference, Los Angeles, California, 24-26 August 1964).

The minimum effort theory is concerned with guiding a vehicle to a specified rms terminal accuracy in the presence of random injection and measurement errors with a minimum expected amount of total velocity correction. It is directly applicable to the case of variable time of arrival terminal control, assuming that the errors are confined to the transfer plane and that the correction mechanization errors are negligible. The purpose of this paper is to apply this theory to the study of guidance problems in typical interplanetary trips. A computer program is developed that performs a linear error analysis of typical interplanetary trajectories with assumed rms injection errors and measurement histories, and that computes a trajectory correction strategy using impulsive corrections whose magnitude and spacings are chosen to approximate the ideal continuous strategy. The analysis of these near optimum discrete strategies extends the study by a Monte Carlo simulation to include the effect of correction mechanization errors, as well as the effect of varying the time of the last correction.

642. Lockheed Missiles and Space Co., Sunnyvale, California, A STUDY OF INTERPLANETARY TRANSPORTATION SYSTEMS, FINAL REPORT by S. Ross, 2 June 1962, Report 3-17-62-1, N63-14679, Contract NAS8-2469 (Unclassified).

The major criteria for planning of manned interplanetary missions are investigated. The following areas are covered: nonstop interplanetary round trips; stopover interplanetary round trips; space missions launched normal to the ecliptic; precise trajectory calculations and the investigation of guidance sensitivities; and nonstop trips passing both Mars and Venus.

643. Lockheed Missiles and Space Co., Sunnyvale, California, THEORY OF MINIMUM EFFORT CONTROL by J. V. Breakwell, H. E. Rauch, and F. F. Tung, January 1966, NASA CR-378, N66-16088, Contract NAS1-3777 (Unclassified).

This report is concerned with optimum guidance for interplanetary missions using either a high thrust or a low thrust engine. The guidance problem is formulated as a problem in optimum control theory, and control theory techniques are applied to its solution. The solution is first presented for the case where: (1) only one component of the position at the terminal time is to be specified,(2) the information rate histories are specified in advance,(3) there is negligible engine mechanization error and, (4) the magnitude of the control is linearly related to the predicted miss distance. The solution is then extended to four separate cases, namely: (1) the rms value of more than one terminal component is specified,(2) the information rate histories (i.e., the rate of measurement and the type of observations) are to be optimized, (3) engine mechanization errors are taken into account and, (4) nonlinear feedback is allowed.

644. Lukes, D., APPLICATION OF PONTRYAGIN'S MAXIMUM PRINCIPLE IN DETERMINING THE OPTIMUM CONTROL OF A VARIABLE-MASS VEHICLE, ARS Journal, 9 August 1961 (ARS Reprint 1927-61).

This paper was presented at the Guidance, Control, and Navigation Conference 7-9 August 1961, Stanford University. Its purpose is to illustrate mathematical techniques by which Pontryagins's maximum principle can be applied to determine optimum control of systems with boundary conditions. To demonstrate the procedure, the author considers the problem of how to regulate the thrust vector of a variable-mass space vehicle to transfer the vehicle from an initial point in space with prescribed initial velocity and mass to a prescribed final position and velocity, minimizing the amount of propellant consumed. The vehicle is assumed to operate in a three-dimensional central gravitational field and the method of optimization allows the minimization to be performed over the class of bounded, piecewise-continuous thrust.

645. Magness, T. A., Pace, W. H., Jr., Penzo, P. A., Steiner, P., and Tompkins, E. H., TRAJECTORY AND GUIDANCE CONSIDERATIONS FOR LUNAR RETURN MISSIONS, London, Academic Press, Inc., 1963, pp. 659-686, A63-23442, Contract NAS7-100 (American Rocket Society, Lunar Missions Meeting, Cleveland, Ohio, 17-19 July 1962, Technology of Lunar Exploration, Progress in Astronautics and Aeronautics, Vol. 10).

Examination of the trajectory and guidance problems involved in returning a spacecraft from the lunar surface to Earth is discussed. A generalized mission is considered to display the guidance requirements, tradeoffs, and problem areas for the return of a spacecraft having all sophistication necessary to achieve manned reentry conditions. An autopilot-accelerometer cutoff launch guidance system and a present state-of-the-art inertial guidance system are utilized.

646. Martin Co., Baltimore, Maryland, FEASIBILITY STUDY OF TWO-BODY MIDCOURSE GUIDANCE, FINAL REPORT, September 1963, NASA CR-55031, ER-13138, N64-12033, Contract NAS1-2501 (Unclassified).

The feasibility of guiding a spaceship with high accuracy and reasonable fuel expenditure in cislunar space by means of two-body equations is demonstrated. The technique presented computes a two-body trajectory using an appropriate virtual mass fixed on the Earth-moon line to replace the combined effects of the Earth and moon. On approach to either Earth or moon, the virtual mass is located at the center of the target body and the magnitude is adjusted to correct for the in-plane variation in the actual pericenter radius.

647. Martin Co., Baltimore, Maryland, OPTIMAL GUIDANCE AND CONTROL SYNTHESIS FOR MANEUVERABLE LIFTING SPACE VEHICLES by G. Kovatch, July 1964, X65-13595 (Aerospace Corporation, Transactions of the 9th Symposium on Ballistic Missile and Space Technology, Vol. 1, 1964, pp. 327-379, X65-13584) (Unclassified).

Not abstracted.

648. Massachusetts Institute of Technology, Experimental Astronomy Laboratory, Cambridge, Massachusetts,
INTERPLANETARY MIDCOURSE GUIDANCE ANALYSIS, VOLUME I by R. G. Stern, 10 May 1963, NASA CR-51827, N64-26866, Grant NsG-254-62, Contracts NAS9-153, AF-04(647)-303 (Unclassified).

This thesis deals with the midcourse guidance correction of the path of an interplanetary vehicle by means of several intermittent thrust impulses. The analysis is linearized by assuming that the vehicle's actual path differs only from a known precomputed reference path. The difference between these two paths is known as the variant path. The linearized equations of motion are those in which the dependent variables are the position and velocity components of the variant path. Emphasis is placed on the analytic solution of the linearized equations of motion. Two distinct methods are developed for this solution when the reference trajectory is an ellipse. The first method involves the separation of the sixth-order system into two independent systems, one of the fourth order and the other of the second order. Although the two independent systems have variable coefficients, both are integrated in closed form. The second method utilizes variational techniques to determine the effect on the path of small variations in a set of six orbital elements. The two solutions are shown to be mathematically equivalent. The analytic solution is used to obtain closed-form expressions for the elements of all the matrices appearing in the guidance system. A midcourse guidance system is outlined that utilizes the analytic results of this theoretical investigation.

649. Massachusetts Institute of Technology, Experimental Astronomy Laboratory, Cambridge, Massachusetts,
OPTIMIZATION OF MIDCOURSE VELOCITY CORRECTIONS by R. G. Stern and J. E. Potter, November 1965, NASA CR-69881, RE-17, Grant NsG-254-62, N66-16182 (Presented at the Symposium on Automatic Control in the Peaceful Uses of Space, Sponsored by the International Federation of Automatic Control, Stavanger, Norway, 21 June 1965) (Unclassified).

A method described to determine the optimum time at which to apply a single midcourse velocity correction is particularly adaptable to variable-time-of-arrival guidance.

By exploiting the critical-plane coordinate system, a single curve can be prepared prior to flight to give the optimum correction time as a function of a miss parameter determined from in-flight navigational measurements. A method is also presented for determining an optimum schedule for midcourse corrections, for which the sum of the magnitudes of all the corrections is minimized. Since there are only two constraints at the nominal time of arrival in position-constrained variable-time-of-arrival guidance, there can be a maximum of two corrections in the optimum schedule. The ranges of miss parameter in which these two corrections are preferable, along with times and components of the corrections, are determined by a geometric model based on the theory of convex sets. In effect, the concept of a six-dimensional state space is used to develop the fundamental equations of linearized midcourse guidance. The control action taken is determined by the predicted miss vector.

650. Massachusetts Institute of Technology, Experimental Astronomy Laboratory, Cambridge, Massachusetts,
SINGULARITIES IN THE ANALYTIC SOLUTION OF THE LINEARIZED VARIATIONAL EQUATIONS OF ELLIPTICAL MOTION by R. G. Stern, AIAA Paper-64-398, Grant NsG-254-62, N64-27326, Contract NAS9-153 (Presented at the 1st AIAA Annual Meeting, Washington, D. C., 29 June - 2 July 1964) (Unclassified).

A series of three second-order differential equations is presented, and the singularity conditions thereof are discussed. Lamber's theorem is used to interpret the X = 0 type of singularity. The time of flight for a one-way trip from Earth to Mars is plotted, and fixed-time-of-arrival guidance allowed for in the correction of vehicular trajectories. When the nature of the space mission is such that time of arrival need not be rigidly constrained, velocity correction may be expressed in terms of only two components of the predicted position variation at arrival time.

651. Massachusetts Institute of Technology, Instrumentation Laboratory, Cambridge, Massachusetts,
A GENERAL, EXPLICIT, OPTIMIZING GUIDANCE LAW FOR ROCKET-PROPELLED SPACEFLIGHT by G. W. Cherry, A64-23821 (American Institute of Aeronautics and Astronautics, and Institute of Navigation, Astrodynamics Guidance and Control Conference, Los Angeles, California, 24-26 August 1964, Paper 64-638) (Unclassified).

Report on the E-Guidance method of providing a universal solution to the many kinds of boundary-value problems encountered in powered-flight guidance is discussed. The derivation of the steering laws, said to be extremely simple and to avoid the use of difficult or specialized mathematics, has as an essential feature the E matrix, which maps the separation between the current boundary conditions and the desired boundary conditions into thrust-allocation guidance coefficients. These coefficients determine the required allocation of thrust acceleration along controlled coordinate axes. The guidance laws, according to the author, can control final coordinates of position in addition to final components of velocity, and control throttlable in addition to fixed-thrust rockets. Because of the generality of E-Guidance, the method is thought to be particularly applicable to many-faceted complex space missions. A universal powered-flight program is described which provides for each type of problem by linking the appropriate set of stored-program subroutines. The E-Guidance program utilizes the switching, branching, and decision-making capabilities of a digital computer.

652. McAllister, D. F. and Schiring, E. E.,
OPTIMIZING THRUST VECTOR CONTROL FOR SHORT POWERED FLIGHT MANEUVERS, American Astronautical Society, 1965, pp. V-1 to V-32, A65-34483 (Space Electronics Symposium, Proceedings of the Joint American Astronautical Society and Aerospace Electrical Society Meeting, Los Angeles, California, 25-27 May 1965, A65-34466).

This paper is a discussion of some considerations involved in the application of optimal control theory to simple thrust vector control systems. Optimal thrust vector control systems are derived for various performance criteria, where the final time of the process is considered to be both fixed and infinite. Considerations of which optimal controller is "best" are

given with respect to practical controller implementation, noise response, and final errors. The problem of thrust vector control for a Mars orbit capture maneuver is also considered as an example, and an error analysis is given of three simple guidance and control schemes. The theory is applied to the rigid-body problem in which body bending, propellant sloshing, and other similar effects are not included. With this assumption, the results obtained are analytical, and the effects of practical implementation, noise response, and final errors can be shown without undue complexity.

653. McDonnell Aircraft Corporation, St. Louis, Missouri, OPTIMUM DIGITAL ADAPTIVE ATTITUDE CONTROL SYSTEM FOR SPACE VEHICLES, FINAL REPORT by J. C. Bowers, 6 January 1964, NASA CR-53109, A405, N64-16748, Contract NASw-614 (Unclassified).

The feasibility of the optimum digital adaptive attitude control system (ODAACS) was demonstrated by the results obtained from the simulation performed in this investigation. The most extreme changes in system parameters did not cause control instability, since the control program is designed to make the optimum decision based upon the measured state of the plant and to correct for any errors in the previous decision. The accommodated torque-to-inertia ratio range is a function of the ODAACS design. The design of the ODAACS control program, for a particular application, is simply the choice of θ_{L_2}, θ_C, and ρ for the particular maximum and minimum acceleration anticipated. θ_{L_2} are the attitude control limits, θ_c is the limit cycle box, and ρ is a fixed number. The selection of θ_L, the rate limit for fuel consumption, is predicted on the tradeoff between fuel consumption and speed of response. Theoretically, there is no limit to either the range of accelerations or torque-to-inertia ratio that the ODAACS can control. Limit cycle control parameters are determined by the required attitude control limits and minimum pulse available (θ_n and θ_p). The selection of θ_n and θ_p is influenced also by the anticipated bias torque. Input data must have a basic resolution of 12 bits to maintain accurate control.

654. McDonnell Aircraft Corporation, St. Louis, Missouri, OPTIMUM DIGITAL ADAPTIVE ATTITUDE CONTROL SYSTEM FOR SPACE VEHICLES, FIRST QUARTERLY REPORT by J. C. Bowers, 15 July 1963, Report A005, X63-15178, Contract NASw-614/SC-4734 (Unclassified).

Not abstracted.

655. McElhoe, B. A., MINIMAL-FUEL STEERING FOR RENDEZVOUS HOMING USING PROPORTIONAL NAVIGATION, ARS Journal, Vol. 32, October 1962, pp. 1614-1615.

Not abstracted.

656. Meditch, J. S., ON THE PROBLEM OF OPTIMAL THRUST PROGRAMMING FOR A LUNAR SOFT LANDING, IEEE Transactions on Automatic Control, Vol. AC-9, No. 4, October 1964, pp. 477-484.

The problem of minimal fuel thrust programming for the terminal phase of a lunar soft landing mission is shown to be equivalent to the minimal time problem for the mission. The existence of an optimal (minimal fuel) thrust program for the problem is then assured by appealing to existence theorems for time optimal controls, and the optimal thrust program is developed by application of the Pontryagin maximum principle. It is shown that the optimal thrust program consists of either full thrust from the initiation of the mission until touchdown, or a period of zero thrust (free-fall) followed by full thrust until touchdown. An approximate switching function which is adequate for a large number of cases is derived, and a preliminary system design is presented.

657. Melbourne, W. G. and Sauer, C. G., Jr., CONSTANT-ATTITUDE THRUST PROGRAM OPTIMIZATION, AIAA Journal, Vol. 3, No. 8, August 1965, pp. 1428-1431.

Analysis is presented for optimization of space vehicle thrust program with prespecified directions of thrust and numerical comparison in vehicle performance between constant-attitude thrust program and optimum variable direction program by means of series of Earth-Mars rendezvous and flyby trajectories, using a power-limited propulsion

system. It is shown that a constant-attitude thrust program with two or more optimized thrust directions is competitive in vehicle performance with a variable direction program for interplanetary mission.

658. Melbourne, W. G. and Sauer, C. G., Jr., OPTIMUM INTERPLANETARY RENDEZVOUS WITH POWER-LIMITED VEHICLES, AIAA Journal, Vol. 1, January 1963, pp. 54-60, A63-11902.

This paper contains a presentation of rendezvous trajectories from Earth to Mars for various flight times and launch dates during 1968-1971, based on optimum-thrust programs for power-limited propulsion systems. The manner in which the propulsion requirements vary with flight time and launch data is considered, and a comparison of vehicle performance using the variable- and constant-thrust programs is presented. The existence of optimum launch dates is interpreted in terms of certain transversality conditions derivable from the calculus of variations. A brief comparison of the advanced propulsion vehicle and the ballistic vehicle propulsion requirements is made for Earth-Mars rendezvous trajectories.

659. Minneapolis-Honeywell Regulator Co., STUDY OF SELF-EVALUATING STATE VECTOR CONTROLLERS WITH APPLICATIONS TO FLEXIBLE LIQUID-FUELED AERIAL AND SPACE VEHICLES by J. T. VanMeter, C. R. Stone, and C. W. Johnson, 21 March 1960, Honeywell R-RD 6156 (Unclassified).

This document describes a comprehensive study of optimal control of high-order systems with multiple control inputs which has been underway for more than a year under internal funding in the Research Department of the Honeywell Military Products Group. It discusses the nature of the problems which have yet to be solved and the approaches which currently seem most promising for their solution. This document proposes a specific 12-month program of research, and indicates the results which may be expected upon completion of this work.

660. Moiseyev, N. N. and Lebedev, V. N.,
SURVEY OF WORKS CARRIED OUT IN COMPUTATIONAL CENTER OF ACADEMY OF SCIENCES OF USSR ON THE THEORY OF OPTIMAL CONTROL OF SPACECRAFT (Foreign Title not Available), Translated into English from Russian by Air Force Systems Command, Foreign Technology Division, Wright-Patterson Air Force Base, Ohio, Report FTD-MT-65-123, AD-615 857, N65-29614, 25 May 1965.

Two approaches to the solution of variational problems of spacecraft control are demonstrated. Problems using the principle of the maximum were discussed, and a very high accuracy of calculations was obtained. All calculations were carried out with very high degree of accuracy and in this sense the given results have a "final character". Methods of dynamic programming require a considerably smaller number of "machine hours". For their use there is no necessity to have a good first approximation. However, they are inferior to classical methods in the sense of accuracy. Schemes of only the first order of accuracy, equivalent to the scheme of integration of Euler, were considered.

661. Moskowitz, S. E.,
ON ACCURACY OF APPROXIMATE THRUST STEERING SCHEDULES IN OPTIMAL CORRECTIONAL MANEUVERS, Astronautica Acta, Vol. 9, No. 1, 1963, pp. 20-30.

In interplanetary travel it will be necessary for spaceship to engage in correctional maneuver to neighboring trajectory to improve its subsequent dynamic behavior. It is obligatory to perform flight with least expenditure of fuel. For correctional maneuver, standards of approximation are developed by which extent of proximity to true or exact values can be ascertained numerically for dependent variables and burning time. Numerical verification is given by examining example and comparing results with exact solution, obtained by numerical integration.

662. Mullen, J. A.,
OPTIMAL FILTERING FOR RADAR DOPPLER NAVIGATORS, IRE International Convention Record, Vol. 10, Pt. 5, 1962, pp. 40-48 (Aerospace and Navigational Electronics).

Optimal filter to estimate center frequency of Gaussian signal in Gaussian noise background is found under conditions appropriate for Doppler navigator application; optimum estimation error for class of signal spectra of differing rates of fall-off on skirts; and optimum is about three times better (on fluctuation error comparison) than currently available discriminators.

663. National Aeronautics and Space Administration,
A STUDY OF STATISTICAL DATA-ADJUSTMENT AND LOGIC TECHNIQUES AS APPLIED TO THE INTERPLANETARY MIDCOURSE GUIDANCE PROBLEM by A. L. Friedlander, 1961, NASA TR R-113 (Unclassified).

A statistical analysis and evaluation of the effect of data-adjustment and decision techniques on the efficiency of midcourse guidance maneuvers are presented. A potentially self-contained optical navigation scheme is hypothesized, and all random measurement errors are considered specified by Gaussian distributions. The basic guidance equations are developed using linear perturbations methods. The nature of the data-adjustment procedure is that the accuracy of terminal prediction improves successively from one guidance point to the next.

664. National Aeronautics and Space Administration,
A STUDY OF THE EFFECT OF ERRORS IN MEASUREMENT OF VELOCITY AND FLIGHT-PATH ANGLE ON THE GUIDANCE OF A SPACE VEHICLE APPROACHING THE EARTH by J. A. White, October 1961, NASA TN D-957 (Unclassified).

A study has been made to determine the effect of errors in measuring velocity and flight-path angle, in applying the corrective thrust, and in the initial predicted perigee altitude upon the guidance of a space vehicle to a desired perigee altitude. Corrective impulses were applied only when the vehicle's predicted perigee altitude was not within a deadband about the desired perigee altitude. The method of scheduling observation points along the trajectory was to make an

observation (and to apply a correction if needed) each time the true anomaly increased a given amount.

665. National Aeronautics and Space Administration, A STUDY OF THE GUIDANCE OF A SPACE VEHICLE RETURNING TO A BRAKING ELLIPSE ABOUT THE EARTH by J. A. White, January 1960, NASA TN D-191 (Unclassified).

A study has been made to determine the most efficient method of scheduling and applying corrective impulses along the trajectory of a space vehicle returning to a braking ellipse about the Earth. The Monte Carlo technique was used to study the relative performance of three methods of scheduling corrective thrust impulses in the presence of various assumed inaccuracies in measuring velocity and flight-path angle and in obtaining the desired thrust impulse. The three methods of scheduling corrective thrust impulses were to apply corrections: (1) at given radial increments, (2) at given times from perigee, and (3) at given increments of the angle between the radius to the vehicle and the perigee radius. These methods were compared in terms of errors in perigee altitude and the total corrective velocity required.

666. National Aeronautics and Space Administration, AN EXPLORATORY STATISTICAL ANALYSIS OF A PLANET APPROACH-PHASE GUIDANCE SCHEME USING ANGULAR MEASUREMENTS WITH SIGNIFICANT ERROR by A. L. Friedlander and D. P. Harry, III, September 1960, NASA TN D-471 (Unclassified).

An analytical and statistical analysis of vehicle guidance during the approach to a planet is presented. The target of guidance is defined in terms of a perigee distance. A simplified navigation scheme is hypothesized using appropriate instrumentation to determine range to the planet and a reference angle in the trajectory plane. Guidance initiation and the number of corrections are varied parametrically to determine optimum values. Nondimensional results, applicable to any planet, are evaluated primarily on the basis of final guidance accuracy and corrective velocity-increment requirements.

667. National Aeronautics and Space Administration, ANALYSIS OF CLOSE LUNAR TRANSLATION TECHNIQUES by J. N. Sivo, C. E. Campbell, and V. Hamza, 1962, NASA TR R-126 (Unclassified).

An analysis of translational maneuvers near the lunar surface is presented. The relative merits of each type of maneuver are discussed on the basis of theoretical fuel consumption and time required for the maneuver. Equations and charts embodying these results are compiled herein to facilitate estimation of the fuel and time requirements for various translational maneuvers.

668. National Aeronautics and Space Administration, CONTACT TRANSFORMATIONS AND THEORY OF OPTIMAL CONTROL by R. S. DeZur and G. W. Haynes, September 1965, NASA CR-306 (Unclassified).

This paper shows that Hamilton-Jacobi theory is inadequate, not because of discontinuities introduced by bounded controls, but because of lack of sufficient conditions required to resolve singular problem. A new system of partial differential equations characterizing control problem with an enlarged control set has been derived in conjunction with new optimization procedure.

669. National Aeronautics and Space Administration, EXPLORATORY STATISTICAL ANALYSIS OF PLANET APPROACH-PHASE GUIDANCE SCHEMES USING RANGE, RANGE RATE AND ANGULAR RATE MEASUREMENTS by D. P. Harry, III and A. L. Friedlander, March 1960, NASA TN D-268 (Unclassified).

Analytical and statistical analysis of guidance for the approach to a planet using angular-rate measurements with errors is presented. Results indicate control logic with "damping", a dead band, high numbers of corrective actions, and no cutoff as preferable. Guidance with accuracies of the order required for atmospheric reentry is feasible with instrumentation of present-day accuracy, but at a cost of one-tenth escape velocity. However, control engines must be capable of producing of the order of one g acceleration of the vehicle.

670. National Aeronautics and Space Administration,
OPTIMAL FILTERING AND LINEAR PREDICTION APPLIED TO A MIDCOURSE NAVIGATION SYSTEM FOR THE CIRCUMLUNAR MISSION by J. D. McLean, S. F. Schmidt, and L. A. McGee, March 1962, NASA TN D-1208 (Unclassified).

The navigation system studied uses the trajectory estimation procedure described in NASA TN D-1205. Onboard optical measurements of the Earth and moon provide the data for the trajectory determination, and linear prediction and a fixed time of arrival guidance law are utilized to compute the necessary corrective velocity impulses. The results of a digital simulation of the complete navigation system are presented in terms of miss distances at perilune and perigee and also the cumulative fuel consumption for velocity corrections. Variations in the root-mean-square errors in optical measurements, injection conditions, and velocity corrections were also considered.

671. National Aeronautics and Space Administration, Ames Research Center, Moffett Field, California,
APPLICATION OF STATISTICAL FILTER THEORY TO THE INTERPLANETARY NAVIGATION AND GUIDANCE PROBLEM by J. S. White, G. P. Callas, and L. S. Cicolani, March 1965, N65-17334, NASA TN D-2697.

The results of a study are presented wherein the Kálman filtering technique is applied to interplanetary navigation and guidance. The study considers the number, type, and timing of observations to be made, and the number and timing of velocity corrections. Both fixed time-of-arrival guidance and a periapse-control guidance are considered. The results are presented principally in terms of uncertainty on arrival, miss on arrival, and magnitude of velocity increments required. It is shown that the observations can be restricted to sextant measurements of the target planet, the launch planet, and the moon (when in the vicinity of the Earth), and that daily observations are desirable during the major portion of the flight, with a much more frequent observation schedule at each end. Four velocity corrections should be made which, with a periapse-control guidance law, use a total of 30 m/sec velocity increment for each leg of the mission, resulting in a miss in the radius of periapse of 4 to 5 km.

672. National Aeronautics and Space Administration, Manned Spacecraft Center, Houston, Texas,
THREE-DIMENSIONAL TRAJECTORY ANALYSIS OF NON-STOP ROUND-TRIP MARS MISSION BETWEEN 1970 AND 1988 USING PROPULSIVE-GRAVITY TURNS WITH ATMOSPHERIC EFFECTS by B. J. Garland, August 1965, X65-37476, NASA TM X-1122 (Unclassified).

Not abstracted.

673. National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama,
PROGRESS REPORT NO. 3 ON STUDIES IN THE FIELDS OF SPACE FLIGHT AND GUIDANCE THEORY 15 JUNE - 20 DECEMBER 1962 by E. D. Geissler, 6 February 1963, MTP-AERO-63-12, N63-16801, NASA TM X-50077.

CONTENTS

674. National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama,
SPACE VEHICLE GUIDANCE - A BOUNDARY VALUE FORMULATION by R. W. Hunt and R. Silber, 8 June 1964, N64-27240, NASA TM X-53059.

A mathematical formulation of the problem of guiding one stage of a space vehicle is given as a boundary-value problem in differential equations. One approach to the solution of this problem is to generate the Taylor's series expansion (in several variables) about a known solution. The theoretical nature of such solutions is discussed, and a method for numerically computing them is presented. This method entails the numerical integration of an associated system of differential equations and can be used to obtain the solution to any desired degree of accuracy for points in a region to be defined. An extension of the method to the problem of guiding several stages of a space vehicle is also given, employing fundamental composite function theory.

675. North American Aviation, Inc., Space Sciences Laboratory, Downey, California,
RENDEZVOUS POSSIBILITIES WITH THE IMPULSE OF OPTIMUM TWO-IMPULSE TRANSFER by D. F. Bender, 15 December 1962, N63-16807, National Aeronautics and Space Administration, Marshall Space Flight Center, Progress Report No. 3 on Studies in the Fields of Space Flight and Guidance Theory 15 June - 20 December 1962, 6 February 1963, pp. 138-153, N63-16801, Contract NAS8-1582.

Not abstracted.

676. Northrop Space Laboratories, Research and Analysis Section, Huntsville, Alabama,
GUIDANCE SYSTEM ERROR STUDY TECHNICAL SUMMARY REPORT by J. E. Hilliard, D. Raney, F. W. Roberts, and B. D. Seagren, 21 May 1965, NAS8-11431, X65-17060, NASA CR-63561, E20-91 (Unclassified).

Not abstracted.

677. Platonov, A. K., Dashkov, A. A., and Kubasov, V. N., OPTIMIZATION OF FLIGHT CONTROL OF SPACECRAFT, Translated into English from Russian by Air Force Systems Command, Foreign Technology Division, Wright-Patterson Air Force Base, Ohio, FTD-MT-65-125, 19 May 1965, AD-615 858, N65-29697.

In this report are investigated properties of optimum processes of flight control of spacecraft in the case when there is available complete information about motion, and when control is produced with the purpose of maintaining given values of certain functionals on the trajectory. Such functionals can be parameters of the trajectory characterizing conditions of encounter with a planet or another apparatus in outer space, or parameters determining spatial position of apparatus at a fixed moment of time.

678. Pokrovskaya, S. A., ON SOLUTION OF THE THREE-DIMENSIONAL PROBLEM OF HELIOCENTRIC INTERPLANETARY FLIGHT WITH A CONSTANT-POWER ENGINE USING THE METHOD OF QUICKEST DESCENT, <u>Cosmic Research</u>, 13 January 1965, pp. 66-74, N65-15435, N65-15432.

Acceleration programs and the trajectories corresponding to them that are optimum in the sense of minimizing

$$I = \int_0^t a^2(t)dt,$$

where a(t) is the thrust acceleration and t is the time of the flight, are determined in the three-body problem of interplanetary flight. The variational problem is solved by the method of quickest descent. Numerical results are presented for the case of Earth-to-planet-to-Earth flights with the terminal velocities made equal.

679. Polack, P.,
APPLICATION OF THE MAXIMUM PRINCIPLE TO THE GUIDANCE AND THE LOCATION OF SPACE SYSTEMS, III (Application du Principe du Maximum au Guidage et a la Localisation des Systemes Spatiaux, III), Technique et Science Aeronautiques et Spatiales, May-June 1965, pp. 225-231, A65-36836 (In French).

Mathematical determination of a method for analyzing the data relative to the available measurements in such a manner as to minimize the variation in the estimation of errors, with reference to a space vehicle equipped with three accelerometers and three radar antennas. In defining the state of any system, three types of information are generally used - theoretical knowledge (on which the mathematical model of the system is based), measurements, and statistical relationships. It is assumed that the magnitudes on which the mathematical model are based can be classified into four categories: (1) measurements all of which can be related at any instant to the components of a vector, (2) magnitudes which are defined as to spectra, or in other words, which can be related to known autocorrelation functions, (3) ordinary unknowns all of which can be expressed as an x(t) characteristic state of the system at the instant t, and (4) known functions or constants. A solution for the problem in limited time is developed based on matrix analysis.

680. Polack, P.,
APPLICATION OF THE PRINCIPLE OF THE MAXIMUM TO THE GUIDANCE AND THE LOCALIZATION OF SPACE SYSTEMS, I (Application du Principe du Maximum au Guidage et a la Localisation des Systemes Spatiaux, I), Technique et Science Aéronautiques et Spatiales, January-February 1965, pp. 45-50, A65-25037 (In French).

Simultaneous study of two apparently distinct problems which, from the purely mathematical aspect, respond to very similar methods. The first problem consists of investigation of a process of treatment of available measures supplying a minimum variance associable with the estimation error of the system analyzed. The second problem consists of investigation of a policy of utilization permitting the approach of a system toward a final state specified in advance and at the lowest cost. It is obvious that the concept of the optimum is

involved in both propositions. Some mathematical principles are presented which result in the systematic generation of optimal solutions of differential systems. The questions raised are considered to be closely related to the theory of systems of localization, guidance, and navigation on one hand and, on the other, calculations of performance.

681. Potter, J. E. and Stern, R. G.,
STATISTICAL FILTERING OF SPACE NAVIGATION MEASUREMENTS, Progress in Astronautics and Aeronautics, Vol. 13, 1964, pp. 775-801.

Criteria used in designing estimators that compute state vector of space vehicle from navigational measurements are compared; under assumption of linearity all criteria lead to same estimator (or filter); if all measurement uncertainties have Gaussian distributions, estimate obtained from optimum filter theory is identical with maximum likelihood estimate; and proof is presented that Bayes estimator, which is biased in favor of initial conditions, leads to same result that would be obtained from unbiased estimator to which six pseudo-measurements, representing initial conditions, have been added.

682. Purdue University, School of Electrical Engineering, Lafayette, Indiana,
INVESTIGATION OF OPTIMIZATION OF ATTITUDE CONTROL SYSTEMS, QUARTERLY PROGRESS REPORT, 15 SEPTEMBER - 31 DECEMBER 1965 by J. Y. S. Luh, 1965, NASA CR-70482, N66-19043, Contracts NAS7-100, JPL-950670 (Unclassified).

In connection with the soft landing problem, an optimal control problem in phase-coordinate and bounded control processes was studied. The general theory for a linear autonomous system was developed and used to determine a method of optimal control. This was done by deriving an algorithm for expressing the open-loop control law as a time function. The method was applied to the time-optical control of an unstable booster with actuator position and rate limits. The control problem of antenna pointing was also investigated as a stochastic optimal control problem in which the probability that the antenna pointing at the desired direction is maximized. The transition density of the stochastic control

process was computed, and the pursuit problem of Mishchenko and Pontryagin is summarized as part of the solution. A preliminary result is that if the z-process is Markov, then it is also a process with independent increments and the n-process is white noise.

683. Ragsac, R. V. and Titus, R. R.,
ANALYSIS OF PLANETARY FLYBY MISSIONS, North Hollywood, California, Western Periodicals Co., 1963, pp. 572-586, Advances in the Astronautical Sciences, Volume 13, North Hollywood, California, Western Periodicals Co., 1963, pp. 572-586 (American Astronautical Society, Annual Meeting, 9th, Los Angeles, California, 15-17 January 1963), A63-23873.

This paper is a presentation of a method for determining the relationships among the three major planning parameters of an interplanetary transportation system (mass, year in which the flight is launched, and mission duration). These parameters are required in evaluating the effective utilization of manned planetary flyby missions with respect to an overall space program. This approach is demonstrated by integrating a model transportation design with numerous heliocentric transfer trajectory data for Mars and Venus for the period 1970-1975. Multiple-planet nonstop round trips are also included. The analyses yield a set of curves relating vehicle system mass required for Earth orbit to mission duration for reconnaissance flights to Mars and Venus in specified years. The relative merits of each trip are discussed. Optimum mass trips to each planet are determined.

684. Rand Corporation,
AN INTRODUCTION TO THE APPLICATION OF DYNAMIC PROGRAMMING TO LINEAR CONTROL SYSTEMS by F. T. Smith, February 1963, Rand Memo RM-3526, Contract AF-49(638)-700 (Unclassified).

This memorandum discusses the application of dynamic programming to control systems that can be described by linear, time-invariant differential equations, and whose performance may be measured by the value of a quadratic form. The necessary techniques are discussed for obtaining explicit expressions for optimal control vectors as linear, time-varying functions of the system state.

685. Republic Aviation Corporation, Farmingdale, New York, TWO-POINT BOUNDARY-VALUE PROBLEM OF THE CALCULUS OF VARIATIONS FOR OPTIMUM ORBITS by J. Richman, National Aeronautics and Space Administration, Marshall Space Flight Center, Progress Report No. 3 on Studies in the Fields of Space Flight and Guidance Theory, 15 June - 20 December 1962, 6 February 1963, pp. 29-56, N63-16803.

This report contains a description for the solution of the two-point boundary-value problem of the calculus to variations for optimum orbits. The method employed uses Lagrange multipliers and Pontryagin's maximum principle to obtain the decision functions. In addition, two differential correction schemes are described. The first scheme is a "method by forward integration", and the second is an alternate "method by backward integration" that attempts to reduce the difficulties that might be encountered in inverting a differential correction matrix. The optimum orbit is determined by a perturbation method similar to that of Encke and accommodates hyperbolic as well as elliptic orbits. The equations necessary for the generation of a digital-computer program are derived.

686. Rosenbaum, R., CONVERGENCE TECHNIQUE FOR THE STEEPEST-DESCENT METHOD OF TRAJECTORY OPTIMIZATION, AIAA Journal, Vol. 1, July 1963, pp. 1703-1705.

Not abstracted.

687. Rossger, E. and Zehle, H., ON THE OPTIMIZATION OF INTERPLANETARY FLIGHTS WITH LOW-THRUST ACCELERATION (Zur Optimalisierung Interplanetarer Übergangsbahnen mit Kleiner Schubbeschleunigung), Raketentechnik und Raumfahrtforschung, Vol. 7, October-December 1963, pp. 137-141 (In German, with summary in English).

This paper is a discussion of the feasibility of using vehicles with low-thrust acceleration for interplanetary travel. It is indicated that the optimization of interplanetary flights with such vehicles requires a maximum payload for a given vehicle. In this variational problem, the equations of motion of the space vehicle occur as secondary conditions.

Further conditions are imposed on this problem by the technological limitations of propulsion. The limiting cases of both the unlimited and constant thrust are considered. In both cases a distinction is made between the flights with a given launch time in a synodic year and those with an open launch time. This time is to be selected so that the payload becomes absolutely maximum.

688. Schmedeke, W. and Swanlund, G.,
OPTIMALIZING TECHNIQUES FOR INJECTION GUIDANCE, American Rocket Society Journal, 9 August 1961, ARS Reprint 1943-61.

This paper was presented at the Guidance, Control, and Navigation Conference 7-9 August 1961, Stanford University. The class of problems being considered is the determination of optimalizing guidance laws for systems where the trajectories described by the state variables are well predicted. For injection guidance, it is assumed that the actual trajectories are adequately described by perturbation or linear equations of motion about the reference trajectory. The method used to obtain the optimal guidance laws is based on Pontryagin's maximum principle.

689. Schmieder, D. H.,
USE OF CALCULUS OF VARIATIONS METHODS FOR TRAJECTORY OPTIMIZATION AND ADVANCED GUIDANCE CONCEPTS, Braunschweig, Friedr. Vieweg and Sohn, 1962, pp. 272-277, A63-21855 (WGL Tagung, Freiburg im Breisgau, Germany, 10-13 October 1961, Wissenschaftliche Gesellschaft für Luftfahrt, E. V., Jahrbuch, 1961).

This paper is a discussion of the trajectory design and guidance of rocket-propelled vehicles. Calculus of variation methods are described as used in the more refined trajectory optimization and guidance modes demanded by the large vehicles which must economically accomplish a variety of space missions.

690. Sepahban, A. H.,
DIGITAL IMPLEMENTATION OF TIME OPTIMAL ATTITUDE CONTROL, Joint Automatic Control Conference, 4th, University of Minnesota, Minneapolis, Minnesota, 19-21 June 1963, Preprints of Technical Papers, New York, American Institute of Chemical Engineers, 1963, pp. 532-547, A64-11272.

This paper is a description of the manner in which basic digital differential analyzer (DDA) techniques can be used to implement the control functions required in the attitude control of a space vehicle, and presentation of the system characteristics resulting from such a design approach. Techniques used for reducing DDA computational errors are considered. A brief review of the time-optimal control theory is given, showing the basic computational tasks involved in applying the theory to the practical problem of attitude control of a space vehicle, including the limit cycling mode employing a rhombic-shaped dead zone in the vicinity of the phase plane origin. Some adaptive features of the control system are briefly considered.

691. Sepahban, A. H. and Podraza, G.,
DIGITAL IMPLEMENTATION OF TIME-OPTIMAL ATTITUDE CONTROL, IEEE Transactions on Automatic Control, Vol. AC-9, No. 2, April 1964, pp. 164-174.

An experimental single-axis, time-optimal attitude control computer was designed and built using digital differential analyzer (DDA) techniques. A relatively simple digital implementation of the control functions was obtained while holding the computational errors within predetermined limits. To evaluate the capabilities, limitations, and accuracy attainable in digital implementation of such a system, tests were conducted in which an analog computer was used to simulate the dynamics of the controlled vehicle. It was shown that the digital control system performed its function properly, providing a true time-optimal control, and that the computation errors were kept below the design limit. The primary concern of this paper is to show how basic DDA techniques can be used to implement the control functions required in attitude control of a space vehicle and to present the system characteristics resulting from such a design approach. Techniques used for reducing DDA computational errors are also given consideration. It will be seen that the truncation

errors can be minimized and limited to a zero-averaged error to prevent hysteresis or drift effects. Unlike truncation errors, round-off errors cannot be completely eliminated and can cause localized irreversibility of computations (hysteresis effects). In spite of this, harmful drifts of accumulated errors are not produced because of the closed-cycle nature of the control problem as viewed in the error phase plane.

692. No entry.

693. Smith, G. L., Schmidt, S. F., and McGee, L. A., APPLICATION OF STATISTICAL FILTER THEORY TO OPTIMAL ESTIMATION OF POSITION AND VELOCITY ON BOARD CIRCUMLUNAR VEHICLE, National Aeronautics and Space Administration, R-135, 1962.

A theory is employed to develop a method for determining the best possible estimate of position and velocity of space vehicle in mid-course phase of flight; results of computer simulation illustrate performance attainable. An onboard system is visualized in which source of information is arbitrary sequence of observations of space angles, corrupted by measurement errors; and scheme is dynamical time varying filter, implemented by computer, processing incoming data to compute optimal estimate of position and velocity.

694. Sokkappa, B. G., ON OPTIMUM STEERING TO ACHIEVE "REQUIRED VELOCITY", International Astronautical Federation, International Astronautical Congress, 16th, Athens, Greece, 13-18 September 1965, Paper, A66-15928.

Derivation of the required condition that must be satisfied by a fuel optimum guidance law for a system in which in the familiar state Equation (A) is linear and time invariant and $\underline{u}$ is a known function of time is discussed. An explicit steering

equation is derived with the first-order approximations for the constant and linear system. An approximate law is derived, taking into consideration practical computer programming possibilities for a digital computer. Numerical examples are included to indicate the performance of this law in comparison with other steering laws. The results for a constant linear system are compared with optimum solutions obtained with the variational calculus. It is shown that the steering law as derived yields excellent results.

695. Space Technology Laboratories, Inc.,
THE PERFORMANCE ANALYSIS OF BALLISTIC MISSILE OR SPACE VEHICLE INERTIAL GUIDANCE SYSTEMS by A. N. Drucker, May 1961, STL Misc 8 (Unclassified).

Specialized guidance system analysis techniques which optimize the recovery of guidance system performance information from noisy and frequently conflicting test data are discussed in detail. Emphasis is placed on the requirements for high-quality trajectory data on the external instrumentation systems.

696. Striebel, C. T. and Breakwell, J. V.,
MINIMUM EFFORT CONTROL IN INTERPLANETARY GUIDANCE, Institute of the Aerospace Sciences, Annual Meeting, 31st, New York, New York, 21-23 January 1963, Paper 63-80, A63-14604.

Discussed is a formulation of the minimization of the average control effort for a specified rms terminal accuracy, in the presence of initial errors, state measurement errors, and control mechanization errors, as a problem in the calculus of variations.

697. Studnev, R. V.,
CERTAIN PROBLEMS OF OPTIMUM CONTROL OF THREE DIMENSIONAL MOTION OF SPACE VEHICLES (Foreign title not available) Translated into English from Russian by Air Force Systems Command, Foreign Technology Division, Wright-Patterson Air Force Base, Ohio, 25 May 1965, FTD-MT-65-120, AD-615 854, N65-29582.

There are investigated questions of optimum pulse control of the spatial orientation of an axially symmetric space vehicle (SV). It is assumed that control of the SV is carried

out by two pairs of control jets (CJ). One is fastened in the vehicle and creates a moment about the axis of symmetry, and the second pair is fixed in a cardan suspension and can create a moment about any axis orthogonal to the axis of symmetry of the apparatus. The following problems are solved: (1) optimum control of orientation of the axis of rotation which is the axis of symmetry of the SV. There are determined conditions under which control of orientation can be carried out by one pair of CJ fastened in the vehicle, (2) optimum control of orientation of the SV rotating about a principal axis of inertia which is not the axis of symmetry, and (3) optimum control of the spatial orientation of an axially symmetric SV in general.

698. Tuchyner, H. J., OPTIMIZATION OF A MERCURY REACTION FLYWHEEL SYSTEM FOR THREE-AXIS ATTITUDE CONTROL, American Institute of Aeronautics and Astronautics, Summer Meeting, Los Angeles, California, 17-20 June 1963, Paper 63-213, A63-18438.

Included is an optimization study of a space-vehicle three-axis attitude-control system employing mercury reaction flywheels which consist of three uncoupled circular conduits in which the mercury is driven by three independent two-phase coaxial electromagnetic pumps having a single common power supply. Detailed design equations for this system are obtained in terms of performance specifications and critical system dimensions. For arbitrary sets of parameters, optimum designs are synthesized which minimize the total weight of the three-axis control system. These optimum solutions are obtained by means of a searching technique using a digital computer. A comparison is made between these optimum mercury systems and a conventional flywheel system on the basis of performance, system weight, and operating life.

699. Tung, F., AN OPTIMAL DISCRETE CONTROL STRATEGY FOR INTERPLANETARY GUIDANCE, IEEE Transactions on Automatic Control, Vol. AC-10, July 1965, pp. 328-335, A65-34101, Contract NAS1-3777.

Study of the problem of guiding one state of a linear dynamical system to a prescribed rms terminal accuracy in

the presence of injection, measurement, as well as engine-mechanization errors with a minimum average effort is discussed. Orbit corrections are assumed to be mechanized in the form of discrete velocity increments whose areas are proportional to the predicted miss distance. Equations are derived for computing the feedback gains as a function of the correction times. It is then shown how the spacings between successive corrections can be optimized. This is done by outlining a computation procedure based on the theory of dynamic programming. The optimum solution includes the effect of the loss of information caused by the mechanization error. The results are applied to a simple but illustrative example that approximates the terminal phase of an interplanetary trip.

700. Tung, F.,
AN OPTIMAL DISCRETE CONTROL STRATEGY FOR INTERPLANETARY GUIDANCE, <u>IEEE Transactions on Automatic Control</u>, Vol. AC-10, No. 3, July 1965, pp. 328-335.

The problem of guiding one state of a linear dynamical system to a prescribed rms terminal accuracy in the presence of injection, measurement, as well as engine-mechanization errors with a minimum average effort, is considered. Orbit corrections are assumed to be mechanized in the form of discrete velocity increments whose areas are proportional to the predicted miss distance. Equations are derived for computing the feedback gains as a function of the correction times. It is then shown how the spacings between successive corrections can be optimized. This is done by outlining a computation procedure based on the theory of dynamic programming. The optimum solution includes the effect of the loss of information caused by the mechanization error. The results are applied to a simple but illustrative example that approximates the terminal phase of an interplanetary trip. A numerical study is made relating the number of corrections and the required amount of propellant for various terminal accuracies and mechanization errors with typical initial errors. The computer results make evident the improvement of the multiple correction strategy over the design of using only one correction, and seem to indicate that the improvement obtained using more than three to four corrections is negligible. Moreover, it shows that there is an optimum number of corrections for a given size of mechanization error.

701. Tung, F., LINEAR CONTROL THEORY APPLIED TO INTERPLANETARY GUIDANCE, IEEE Transactions on Automatic Control, Vol. AC-9, January 1964, pp. 82-89, A64-15917.

Consideration of the problem of interplanetary guidance in the presence of random injection and measurement errors from the point of view of minimizing the expected value of the square of the control effort to meet a prescribed terminal accuracy is discussed. It is shown that the optimal control signal is a linear function of only those components of the predicted miss whose terminal covariance is specified. A one-dimensional model which approximates the terminal phase of an interplanetary trip is considered in detail. Computer results are given showing the comparison of this solution with the minimum effort theory developed recently by Breakwell and Striebel on the requirement for the expected amount of velocity corrections. An analytical expression is given which shows that the present design is about 13 percent more costly insofar as the terminal portion of the expected velocity requirement is concerned.

702. Tung, F., OPTIMAL DISCRETE CONTROL STRATEGY FOR TERMINAL GUIDANCE, Joint Automatic Control Conference, 22-25 June 1965, pp. 499-507.

Stochastic optimization of guidance of space vehicle, using one state of linear dynamical system by impulsive velocity correction with minimum average effort is discussed. Prescribed rms terminal accuracy is obtained in presence of initial random error, and measurement and engine mechanization errors. Equations are derived for computing feedback gains as function of correction times; theory of dynamic programming is used to show how spacings between successive corrections can be optimized. Results are applied to example that approximates terminal phase of interplanetary trip. Computer results seem to indicate that improvement obtained using more than three to four corrections is negligible.

703. United Aircraft Corporation,
OPTIMUM TRANSFERS BETWEEN HYPERBOLIC ASYMPTOTES by F. W. Gobetz, November 1962, UAC A-110058-5 (Unclassified).

An investigation was made to determine the possible benefits of a single high-thrust impulse during the hyperbolic encounter of a spacecraft with a perturbing planet. In addition to the single-impulse transfers, a four-impulse maneuver is described.

704. University of California, Berkeley, California,
ON SYSTEMS FOR AUTOMATIC CONTROL OF THE ROTATION OF A RIGID BODY by R. E. Mortensen, November 1963, AD-428 440 (Unclassified).

A review is presented of rigid-body dynamics together with a formulation which appears to be especially suitable for treatment by the techniques of Lyapunov and Pontryagin for studies of stability and optimization. From this formulation, which is based on quaternions, the Cayleyrodriquez parameters are developed. These parameters permit the development of the complete dynamical equations for the control problem in a way which suggests a suitable control law for an automatic regulator. The second method of Lyapunov is used to prove that this regulator is asymptotically stable in the large. It is not claimed that the regulator is optimal in any sense. Rather, the purpose is to illustrate how the inherent structure of the dynamical equations plus some insight, based on the anticipated use of Lyapunov's test for stability, can suggest an (A. S. I. L.) control law. Finally, the actual problem of optimization, to which Pontryagin's principle may be applied, is surveyed briefly.

705. University of Southern California, Department of Electrical Engineering, Los Angeles, California,
DISCRETE TERMINAL CONTROL OF SPACE VEHICLES VIA MATHEMATICAL PROGRAMMING, INTERIM TECHNICAL REPORT by N. E. Nahi and L. A. Wheeler, October 1965, USCEE-141, SSD-TR-65-130, AD-473 177, X66-12478, Contract AF-04(695)-746 (Unclassified).

Not abstracted.

706. University of Southern California, Electronics Sciences Laboratory, Engineering Center, Los Angeles, California,
SYNTHESIS OF NEAR-OPTIMAL FEEDBACK CONTROL FOR SPACE VEHICLE SYSTEMS, INTERIM TECHNICAL REPORT by N. E. Nahi and T. S. Bettwy, September 1965, USCEE-142, SSD-TR-65-129, AD-472 542, X66-10185, Contract AF-04(695)-746 (Unclassified).

A procedure for the synthesis of near optimal feedback control for use in space vehicle systems, which meets the requirements of allowable complexity of the controller, and yields an asymptotically stable system is described. The basic idea involved is to obtain the near optimal feedback control by making use of the optimal open-loop control. Analyzed is a physical system which is described by a vector differential equation. All major computations are performed prior to system operation. The technique is valid for nonlinear and linear systems. The scheme is extended to the case where all the states are not directly measured and estimation of the remainder from the measurements is undesirable. Several examples are included.

707. University of Southern California, School of Engineering, Los Angeles, California,
CONTINUOUS IDENTIFICATION OF THE PARAMETERS OF SPACE VEHICLE DYNAMICS by G. A. Bekey, USCEE-138, August 1965, Contract AF-04(695)-746 (Unclassified).

Not abstracted.

708. University of Southern California, School of Engineering, Los Angeles, California,
OPTIMUM TERMINAL CONTROL OF CONTINUOUS SYSTEMS VIA A SIMPLE NUMERICAL ALGORITHM by N. E. Nahi, January 1966, USCEE-156, Contract AF-04(695)-746 (Unclassified).

Not abstracted.

709. Vance, R. J.,
IMPLEMENTATION OF AN OPTIMAL ADAPTIVE GUIDANCE MODE, AIAA Journal, Vol. 3, January 1965, pp. 141-142.

Not abstracted.

710. Vanderbilt University, Nashville, Tennessee,
AN APPLICATION OF CALCULUS OF VARIATIONS TO THE OPTIMIZATION OF MULTISTAGE TRAJECTORIES by M. G. Boyce, National Aeronautics and Space Administration, Marshall Space Flight Center, Progress Report No. 3 on Studies in the Fields of Space Flight and Guidance Theory, 15 June - 20 December 1962, 6 February 1963, pp. 10-28, N63-16802, N63-16801.

A procedure is developed for determining a fuel minimizing trajectory for a multistage rocket in three-dimensional space. In each stage, the fuel burning rate and magnitude of thrust are assumed constant. The motion is subject to the inverse-square gravity law but with negligible atmospheric resistance. The Euler-Lagrange equations determine minimizing trajectories in a given stage. Transversality conditions are then invoked to extend a minimizing path across the boundary to the next stage. The existence of minimizing trajectories is assumed, sufficient conditions not being investigated in this paper.

711. Weiss, D. C.,
A GENERAL DISCUSSION OF EARTH-MARS INTERPLANETARY ROUND TRIPS, Canadian Aeronautics and Space Journal, Vol. 9, October 1963, pp. 259-269, A63-25402, Contract AF-29(601)-2207.

This paper is a presentation of solutions, in the form of continuous plots, for a family of two-dimensional transfer-orbits with sphere-of-influence terminals and circular Earth orbit, for trips to and from Mars near its perigee and mean radius. Although the results are not as rigorous and accurate as those of the proper three-dimensional, three-body (near terminals) analysis, they reflect qualitative relations consistently, and permit a generalized approach to the problem. From these results, the limitations of Hohmann ellipse transfers and the general desirability of fast transfers are apparent. A perigee-kick technique is introduced, and is sometimes found to be most effective for the return transfer. It is also

shown that fuel boiloff and graze reentry capabilities are very significant factors in determining mass-ratio requirements. These effects indicate penalties associated with the use of cryogenic fuels for Earth-Mars missions.

1. Guidance

712. Abzug, M. J.,
FLIGHT MECHANICS; SATELLITE RIGID-BODY DYNAMICS, Aerospace Engineering, Vol. 21, September 1962, pp. 90-91.

Not abstracted.

713. Aerospace Corporation,
AN EXPLICIT METHOD OF GUIDING A VEHICLE FROM AN ARBITRARY INITIAL POSITION AND VELOCITY TO A PRESCRIBED ORBIT by D. MacPherson, 13 February 1961, TDR-594(1565-01)TN-1 (Unclassified).

This paper presents a derivation of an explicit technique for guiding a constant thrust, constant effective exhaust velocity rocket from any initial position and velocity to any preselected orbit compatible with vehicle performance capability. Emphasis is placed on the principles involved rather than on the sophistications and details of mechanization.

714. Aerospace Corporation, El Segundo, California,
SEMI-ACTIVE CONTINUOUS WAVE RADAR FOR TERMINAL GUIDANCE OF SPACE VEHICLES (U) by G. V. Nolde, I. Bekey, and J. G. Barnes, February 1965, TDR-269 (4511-30)-2, AD-363 753, N50131, Technical Operating Report, Contract AF-04 (695)-269 (Secret).

Not abstracted.

715. Aerospace Corporation, Los Angeles, California,
STUDY OF STATION KEEPING USING LOW THRUST (ION) ENGINES by R. V. Soufl, January 1964, TDR-269 (4504-20)-1, TDR-63 374, AD-431 841, Contract AF-04(695)-269 (Unclassified).

The problem of using low thrust engines to control the position, period, and eccentricity of a satellite's orbit is examined. Equations describing the motion of a satellite in response to constant low level radial and tangential thrusting are developed. A guidance logic for control of the position and period is developed using phase plane techniques.

A logic for control of eccentricity is also presented. The problem of orbit determination is also considered. Expressions relating period and position uncertainties as a function of the norminal orbit parameters, tracking errors, and tracking time are developed.

716. Aerospace Corporation, Los Angeles, California, THE COMBINED AERODYNAMIC-PROPULSIVE ORBITAL PLANE-CHANGE MANEUVER by R. W. Bruce, June 1964, TDR-269 (4550-10)-9, TDR-64 98, AD-602 669, Contract AF-04(695)-269 (Unclassified).

Due to the relative expense of the orbital plane-change maneuver when it is accomplished by means of impulsive thrust, other techniques have been sought that would be more economical from the standpoint of required characteristic velocity. Two techniques that make use of combined aerodynamic and propulsive forces have been proposed by London and Nyland. These are reviewed, and their limitations, which are due in part to certain simplifying assumptions made in their analyses, are presented. This investigation demonstrates that both analyses, while valuable because they are presented in close form, are limited to plane changes below 30 to 40 degrees. It is also shown that the combined maneuver is superior to the impulsive-thrust plane change for vehicles with lift-to-drag ratios greater than 1.5 and that the velocity savings that result as a consequence of using such maneuvers are on the order of 4000 to 5000 ft/sec at most. As a result, it is concluded that, for certain situations, the combined aerodynamic propulsive maneuver appears to be an attractive and available means for reducing the characteristic velocity requirement of the orbital plane change.

717. Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio, FEASIBILITY OF A TRACTOR TYPE SELF-MANEUVERING UNIT-MASTER'S THESIS by J. S. Heyde, Jr., August 1964, AD-605 486 (Unclassified).

A small, unstabilized, tractor type, self-maneuvering unit (SMU) is not considered a satisfactory vehicle for extra vehicular travel in space. A pendulum analogy of flight does not prove a satisfactory method of analyzing the space flight characteristics of an unstabilized system because of the

pilots lack of good reference system and thrust direction indicator. A spaceflight simulator study reveals that using pitching and yawing thrust to control the main thrust vector of a stablized SMU, the rendezvous with a T target over distances up to 500 feet is a relatively simple maneuver. No reverse thrust is necessary to reduce terminal velocity because of the small velocity build-up in flight, however, when the conditions of offcenter thrust are simulated by providing a constant roll rate, the percentage of hits on the target is reduced from a mean value of 90 to 17 percent; moreover, the terminal velocity increases to the point where retrothrust is needed to provide a safe landing. The tractor type SMU is a very risky method of transportation which requires a very skilled operator to obtain even minimum success.

718. Air Force Systems Command, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio,
APPLICATION OF AERODYNAMIC LIFT IN ACCOMPLISHING ORBITAL PLANE CHANGE by R. N. Bell and W. L. Hankey, Jr., September 1963, TDR-63 693, AD-427 130, (Presented at the ASD 1963 Science and Engineering Symposium, 18-19 September 1963) (Unclassified).

This study considers the concept of a hypersonic glider-type spacecraft utilizing its aerodynamic maneuvering capability in performing orbital plane change. For lifting vehicles, an optimization procedure is developed which defines the proper vehicle attitude, propulsion utilization, and sequence of operations to produce the maximum plane change for a given fuel expenditure. The results obtained are compared with the fuel requirements for a pure propulsion (nonlifting) plane change while remaining in orbit. Specifically, the optimum bank angle, angle of attack, entry angle, thrust alignment, and thrusting procedures are defined. In addition, the advantages of high L/D vehicles are graphically illustrated. The method is seen to be more efficient than the pure propulsion method, but is found to be far more complex and requires longer times to execute.

719. Air Force Systems Command, Space Systems Division, Inglewood, California,
EXPERIMENT D-9, SIMPLE NAVIGATION ON GEMINI IV by E. M. Vallerie (In NASA, Washington Manned Space Flight Experiment Symposium Gemini Missions III and IV, 1965, pp. 105-119, N65-36100), N65-36108 (Unclassified).

Efforts to develop a manual space navigation and guidance technique which would provide full backup in case of complete power failure, and which could be merged and interfaced with primary automatic systems are reported. A space sextant and a space stadimeter were developed and tested on the Gemini-IV mission to determine their future applicability. Primary concern with the sextant was the field of view necessary to allow the astronaut to readily identify stars. Primary objectives of the experiment focused on (1) evaluating the man-spacecraft operational suitability of the space sextant, and obtaining quantitative data for accessing the limits of accuracy of the sextant for optical rendezvous type measurements and (2) studies of various star and horizon phenomena and specific star-to-horizon measurements to obtain data for postflight calculations and accuracy determinations of navigational position. Although an evaluation of the navigational accuracy using the star-to-horizon measurements has not been completed, valuable qualitative data were obtained on the availability of the observable phenomena, which provided the baseline foundation for successful development of purely manual navigation and guidance techniques.

720. Air Force Systems Command, Wright-Patterson Air Force Base, Ohio,
RADIAL AND BINORMAL THRUSTING TECHNIQUES FOR MANEUVERING SATELLITES IN NEAR EARTH SPACE, REPORT FOR APRIL 1963 - JANUARY 1964 by A. F. Manikowski, May 1964, TDR-64 17, AD-603 699 (Unclassified).

The technique of utilizing radial and binormal continuous thrust for changing the position of a vehicle in a near Earth orbit has been investigated. This study has shown that maneuvering satellites employing electric propulsion have an advantage over a comparative chemical or coldgas system for mission times greater than 20 days. When continuous low thrust is used, the error involved in predicting the position of an evasive satellite is approximately 100 miles, more or less, which depends on the height of the orbit and the thrust level

involved. The orbital rendezvous maneuver requires a fine degree of control over the position of the rendezvous ship. It appears that radial and binormal continuous thrust can be employed to provide this control function. In addition to the mentioned evasive and rendezvous maneuvering, this technique could be applied to a reconnaissance satellite to fulfill the station-keeping function.

721. Army Ballistic Missile Agency, Redstone Arsenal, Alabama, OTIA SPACE STUDY VOLUME IV MILITARY SPACE SYSTEM CAPABILITIES (U), 1 February 1961, Contract DA-04-495-506-ORD-1829 (Secret R/D)

Not abstracted.

722. Author Unknown, COCKPIT UNIT WILL ALLOW GEMINI ASTRONAUTS TO ALTER FLIGHT PLAN, Missiles and Rockets, Vol. 15, No. 8, 24 August 1964, p. 33.

Manual Data Insertion Unit (MDIU), developed by IBM, will permit Gemini pilots to manually change basic data used by guidance computer in controlling flight; through two small panels in cockpit, astronauts can introduce 20 categories of information into computer, including updated altitude and velocity from radar tracking stations, new time to retrograde in event of shortened mission and changes in air density coefficients affecting reentry guidance; cockpit elements of MDIU and operation.

723. Author Unknown, INTERNATIONAL SATELLITE BIBLIOGRAPHY, Biuletyn Polskich Obserwacji Sztucznych Satelitow, December 1964, 99 pp. (In Polish, English, and Russian; A66-12457).

Bibliographic selection that constitutes a part of the International Satellite Bibliography. The subjects covered are:

1) Orbital theory of Earth satellites (influence of the Earth's gravitational field and of the atmosphere, lunar and solar perturbations, and radiation effects).
2) Theory of lunar-satellite motion.
3) Theory of motion of artificial satellites of other planets.

4) Theory of motion of artificial asteroids.
5) Rotational motion of satellites.
6) Methods for calculating orbits (particularly from radio observations).
7) Determination of orbits.
8) Computation of ephemerides.
9) Orbital data.
10) Results of observations.
11) Study of the Earth's gravitational field.
12) Application of artificial satellites in geometrical geodesy.
13) Application of artificial satellites in navigation.
14) Atmospheric studies.
15) Study of solar pressure.
16) Problems in the theory of relativity.

To avoid transliteration, the Russian references are listed separately and in their original spelling.

724. Author Unknown,
ORBITAL FLIGHT HANDBOOK, Space Flight Handbooks, Vol. 1, 1963 (NASA SP-33, Pt. 3).

This book covers the dynamics of space flight in a variety of ways of interest to the mission designer and evaluator. In condensed form, it provides background data and material collected through several years of intensive studies in each mission area. This volume includes guidance and control requirements for orbital flight.

725. Author Unknown,
RESULTS OF SPACE DOCKING TESTS, Engineering, Vol. 196, 13 December 1963, p. 768.

Not abstracted.

726. Author Unknown,
THINKING AUTOPILOT GUIDES X-15 SPACE MACHINE DESIGN, Vol. 34, 2 August 1962, 10 pp.

Not abstracted.

727. Bell Aircraft Corporation,
REMORA - PRELIMINARY DRAFT FOR A MANNED SPACE CAPSULE STUDY, January 1960, D7052-953001 (Unclassified).

Not abstracted.

728. Bell Telephone Laboratories,
CANADIAN ALOUETTE SATELLITE GUIDED INTO ORBIT BY COMMAND GUIDANCE SYSTEM, November 1962 (Unclassified).

Not abstracted.

729. Bell Telephone Laboratories,
COMMAND GUIDANCE PUTS TIROS III IN ORBIT, August 1961 (Unclassified).

Not abstracted.

730. Bell Telephone Laboratories,
LABORATORIES SYSTEM GUIDES NASA SOLAR OBSERVATORY INTO ORBIT, April 1962 (Unclassified).

Not abstracted.

731. Benfield, C. W.,
INERTIAL GUIDANCE AND NAVIGATION, Space/Aeronautics, Vol. 44, No. 2, 1965, pp. 73-76 (A65-33608).

Review of current trends in the designing of inertial guidance and navigation systems. Various devices for achieving low-cost, lightweight, and high-accuracy systems are described, special mention being made of the use of strapdown systems in which gimbals are eliminated and of a gimbaled fourth gyro for improving the reference accuracy of a moving-base platform. The requirements that must be met by inertial systems in SST's and spacecraft are outlined. A number of novel accelerometers capable of sensing very low changes in acceleration levels are described.

732. Blatz, W. J., Pannett, R. F., Salyers, E. L., and Weber, G. J.,
GEMINI DESIGN FEATURES, American Institute of Aeronautics and Astronautics, 1964, pp. 387-400 (In: American Institute of Aeronautics and Astronautics, and NASA, Manned Space Flight Meeting, 3rd, Houston, Texas, 4-6 November 1964, Technical Papers A65-10721).

Description of various features of the Gemini two-man spacecraft. The operation of the Gemini guidance and control system during the different phases of the mission are reviewed. The inertial measurement unit (IMU), which provides both an all-attitude reference and acceleration information, is described as are the on-board digital computer, rendezvous radar, flight control system, and horizon sensor. Progress in the development of the guidance and control system is discussed. The choice and characteristics of a fuel cell for the auxiliary power supply is described, as is the space radiator heat rejection system chosen.

733. Blitzer, F., Bonelle, G., and Kriegsman, B.,
ORBITAL RENDEZVOUS CONTROL, ISA Journal, Vol. 9, No. 8, August 1962, pp. 33-38.

For long distance space missions it is advantageous to assemble and finally prepare the spaceship while orbiting beyond the Earth's atmosphere. As part of the Apollo manned lunar probe, it is planned to connect a fuel laden satellite to a manned ferry at an altitude of 300 nautical miles. The ferry initially will wait in a low altitude orbit coplanar with that of the satellite. When the proper epoch angle between ferry and satellite occurs, the ferry will commence to approach the satellite altitude. The satellite will then be 20 to 30 nautical miles behind and overtaking the ferry at a relative velocity of 350 ft/sec. The ferry will accelerate until this velocity is 25 ft/sec when the main engine will be cut off at a nominal range of 3000 ft. The velocity will finally be reduced to 0.05 ft/sec by a series of pulse from small engines. The requirements of instrumentation to achieve such maneuvers is considered. The basic sensors are three rate-integrating gyroscopes, three accelerometers, a horizon scanner, and a radar. These are described with particular emphasis on the radar. For this application, the use of a microwave f.m./c.w. radar operated in conjunction with a transponder on board the satellite is recommended.

734. Boeing Co., Seattie, Washington,
FLIGHT MECHANICS OF SPACE VEHICLES - A SUMMARY OF TECHNICAL RESEARCH DOCUMENTS, March 1965, 64 pp., D2-23848-1, AD-458 066L (Unclassified).

This document consists of the collected abstracts of documents written by members of the following organizations within the Aerospace Division of the Boeing Company.

1) Flight mechanics and guidance.
2) Flight technology and space mechanics.
3) Applied mathematics.

The documents are concerned with orbit stability, trajectory computation, navigation, guidance, optimization, and attitude control.

735. Breckman, J.,
THEORY AND APPLICATION OF THE B-CHART, Radio Corporation of America Review, Vol. 25, No. 4, December 1964, pp. 769-784.

This report presents a new projection, well suited to a wide class of trajectory and coverage problems in the space era. The Breckman Projection, or B-chart, has the following basic properties:

1) Equal horizontal distances on the chart take an equal time to traverse, whether the trajectory is circular, elliptical, or even nonballistic. The horizontal coordinate may be used interchangeably or simultaneously as longitude or time, and the chart displays a continuous ephemeris of the object.
2) The orbital plane cuts the chart in a vertical line, and this cut moves across the face of the chart at a rate combining Earth rotation, nodal precession, and whatever high derivatives of nodal motion are important.
3) The ground track on the chart is a replica of the angle-versus-time characteristic of the object in its own plane, for any trajectory-circular, elliptical, or arbitrary. Hence, perigee precession is accommodated by vertical shifts of the track with respect to the chart.
4) The fraction of time an orbiting object spends above an arbitrary area on the Earth is numerically equal to that area on the chart. (The chart rectangle has unit area.)

This property makes the charts particularly useful for analyzing and improving the statistical performance of the ground environment against the space population.

736. Bruce, R. W.,
COMBINED AERODYNAMIC-PROPULSIVE ORBITAL PLANE CHANGE MANEUVER, Vol. 3, July 1965, pp. 1286-1289.

Not abstracted.

737. Bryson, A. E. and Denham, W. F.,
GUIDANCE SCHEME FOR SUPERCIRCULAR RE-ENTRY OF A LIFTING VEHICLE, Vol. 32, June 1962, pp. 894-898.

Not abstracted.

738. Carley, R. R. and Cheatham, D. C.,
GEMINI GUIDANCE AND CONTROL, International Astronautical Federation, International Astronautical Congress, 16th, Athens, Greece, 13-18 September 1965, Paper, 44 pp. (A66-15924).

Review of the mission objectives and brief description of the Gemini guidance and control system. The Gemini mission objectives are:

1) Long-duration missions.
2) The development of an operational rendezvous capability.
3) The development and evaluation of controlled reentry capability.
4) The development of flexible systems.

Design considerations discussed include redundancy and reliability, ground monitoring, abort considerations, and guidance and control system implementation. The control and guidance system is shown. The Gemini flights completed have demonstrated the launch guidance capacity, one of the two reentry guidance techniques, orbit maneuvering, and orbit and reentry attitude stabilization and control.

739. Chrysler Corporation,
ORBITAL CAPABILITIES OF A JUPITER - AGENA "B" SPACE VEHICLE (U), 17 January 1961, Chrysler Misc 7 (Secret).

Not abstracted.

740. Citron, S. J.,
SATELLITE LIFETIMES UNDER THE INFLUENCE OF CONTINUOUS THRUST ATMOSPHERIC DRAG AND PLANET OBLATENESS, AIAA Journal, Vol. 1, June 1965, pp. 1355-1360.

Not abstracted.

741. Curkendall, D. W. and Pfeiffer, C. G.,
DISCUSSION OF GUIDANCE POLICIES FOR MULTIPLE-IMPULSE CORRECTION OF TRAJECTORY OF SPACECRAFT, Progress in Astronautics and Aeronautics, Vol. 13, 1964, pp. 667-687.

Three proposed methods of determining when and how to perform one or more impulsive velocity corrections to spacecraft orbit, when there is uncertainty in knowledge of orbit and random errors arise in execution of correction are presented; example is constructed which permits application of all three methods to single problem and numerical results are evaluated.

742. Curtiss-Wright Corporation, Wright Aeronautical Division, Wood-Ridge, New Jersey,
A THEORETICAL AND EXPERIMENTAL PROGRAM TO ESTABLISH AND PROVE A DESIGN FOR A LIQUID PROPELLANT ROCKET ENGINE SYSTEM FOR AN EVASIVE SATELLITE OR A SATELLITE INTERCEPTOR FINAL REPORT, NOVEMBER 1961 - DECEMBER 1963 (U) by W. Q. Walker, September 1964, RPL-TDR-64-50, AD-357623, X65-13701, Contract AF-04 (611)-7424 (Confidential).

Not abstracted.

743. Dusek, H. M.,
THEORY OF ERROR PROPAGATION IN ASTRO-INERTIAL GUIDANCE SYSTEMS FOR LOW-THRUST EARTH ORBITAL MISSIONS, American Rocket Society, Annual Meeting, 17th, and Space Flight Exposition, Los Angeles, California, 13-18 November 1962, Paper 2682-62, 11 pp. (A63-1256).

Analysis, by two methods which supplement each other, of the propagation of position and velocity errors with time in astroinertial guidance systems for low-thrust Earth satellites. First, Hamilton-Jacobi's partial differential equation

is used, since the problem becomes separable in parabolic coordinates. This method yields the regions of possible deviations from the unperturbed trajectory without an explicit knowledge of the perturbed orbits. Second, the differential equations of a first-order perturbation theory in cylindrical coordinates are integrated in closed form, using elliptic orbits of arbitrary eccentricity as unperturbed reference trajectories. A general classification of the possible deviations based upon this explicit solution is given. The errors due to the linearization are briefly discussed with reference to results based upon Hamilton-Jacobi's partial differential equation and the numerical integration of the exact differential equations. An explicit analytical method for the determination of the bias error during the mission is developed.

744. General Electric Co.,
CELESTIAL-INERTIAL GUIDANCE FOR BALLISTIC MISSILES (U) by W. F. Hamilton, 31 January 1961, GE 61TMP-8 (Secret).

The aim of this study was to determine preferred configurations of celestial-inertial guidance systems for ballistic missiles. It includes a classification of system alternatives, an examination of one particular system, and a review of design studies made to date in the industry.

745. General Electric Co., Radio Guidance Operation, Santa Barbara, California,
RADIO GUIDANCE EVALUATION REPORT FOR ATLAS/AGENA LV-3A/01A/7101/4808 (U) by W. F. Hiltz and L. R. Seager, 18 September 1964, WTR-TO-64-014, AD-353 577, X65-11439 Contract AF-04 (695)-476 (Secret).

Not abstracted.

746. General Electric Co., Radio Guidance Operation, Santa Barbara, California,
RADIO GUIDANCE EVALUATION REPORT FOR ATLAS/AGENA LV-3/01A/SV/353D/4811/963 (U) by W. F. Hiltz and L. R. Seager, 30 November 1964, WTR-TO-64-019, X65-11441, Contract AF-04 (695)-476 (Secret).

Not abstracted.

747. Göschel, W. and Wagner, W. U., ATTITUDE CONTROL AND PATH CORRECTION OF SATELLITES AND SPACE PROBES 1, VDI A. (Germany), Vol. 107, No. 20, 864-8, July 1965, pp. 864-868.

Frequently, space missions require the orientation of the vehicles in a prescribed reference direction and a high orbital accuracy of the motion. Holding and gaining of the desired rotational state is subject to the attitude control systems. Changing or keeping of the translational state will be done by path correction or control systems. There are various types of attitude control systems. Some examples show the mode of operation of path correction and control.

748. Gunckel, T. L., AN EXPLICIT RENDEZVOUS GUIDANCE MECHANIZATION, Institute of Electrical and Electronics Engineers, 1963, pp. 112-116 (Seventh National Convention on Military Electronics, New York).

The method described is based on the determination of the correct velocity vector to achieve a free-fall trajectory starting from the present position of the vehicle and passing through the rendezvous point at some specified time. The complete determination of the required velocity, however, depends upon the solution of equations involving numerous square roots and trigonometrical functions and by the time the solution is obtained it is out of date. The difficulty is overcome by utilizing a dual major and minor cycle for the computation. Updating in the minor cycle is effected with partial derivatives and can be completed rapidly. The major cycle, which is slower, corrects for the drift in the minor cycle corrections and updates the partial derivatives. The basic mechanization equations are given and the derivation of those for the major and minor cycles indicated.

749. Hailey, W. C., Mosner, P., and Vandervelde, W. E., PRECURSOR ORBITAL GUIDANCE, Journal of Spacecraft and Rockets, Vol. 1, September - October 1964, pp. 520-525, American Institute of Aeronautics and Astronautics, Guidance and Control Conference, Cambridge, Massachusetts, 12-14 August 1963, Paper 63-321, A64-26580.

Not abstracted.

750. Harvard University, Cruft Laboratories, Cambridge, Massachusetts,
NONLINEAR FEEDBACK SOLUTION FOR MINIMUM RENDEZVOUS WITH CONSTANT THRUST ACCELERATION, TECHNICAL REPORT by A. E. Bryson, Jr., July 1965, TR-478, Nonr 186616, NR373 012, AD-468 164 (Unclassified).

The instantaneous thrust-direction for a spacecraft to perform a minimum-time rendezvous with another (nonmaneuvering) spacecraft is determined as a function of instantaneous relative velocity and position. The magnitude of the thrust acceleration is assumed constant and the acceleration due to external forces is neglected.

751. Hayes, J. E. and Vandervelde, W. E.,
SATELLITE LANDING CONTROL SYSTEM USING DRAG MODULATION, ARS Journal, Vol. 32, May 1962, pp. 722-730.

Not abstracted.

752. Holahan, J.,
GEMINI ELECTRONICS, Space/Aeronautics, Vol. 40, October 1963, pp. 82-89.

Not abstracted.

753. Hu, S. S. and Thompson, M. L.,
A DIRECT AND ANALYTICAL SOLUTION FOR SPACE FLIGHT GUIDANCE FUNCTIONS American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 3rd, New York, New York, 24-26 January 1966, Paper 66-94 (A66-17093, Contract NASw-1165).

The primary purpose of this study was to establish a new technique for obtaining, by analytical methods, polynomial-type guidance functions for optimal space flight. These guidance functions should allow the conversion of current values of the state variables and specified mission parameters into values for the optimum steering directions and cutoff time; they should continually furnish them regardless of previous disturbances to the vehicle's trajectory. To date, an operating analytical solution has not been achieved and the necessary guidance functions are obtained either by near optimum approximations or statistical methods which are applicable to simplified or restricted flight paths. To illustrate this analytical approach, an example in the form of optimum ascent to circular orbit is worked out in detail and results are shown

to agree quite well with those obtained by conventional numerical methods through calculus of variations.

754. Hughes Aircraft Company, El Segundo, California, FLIGHT SIMULATION STUDY FOR SPACE MISSIONS UTILIZING SOLID PROPELLANT CONCEPTS, FINAL REPORT, November 1963, TDR-63 1111, SSD31147R, SDN3 7963122, AD-350 464 (Secret).

Not abstracted.

755. Institute for Defense Analyses, Manned Orbital Laboratory, Arlington, Virginia, PRE-PROGRAM DEFINITION CONSIDERATIONS, VOLUME II, August 1964, 5D50 T16, AD-358 867L (Secret).

CONTENTS

Reconnaissance Technology

- Photographic Reconnaissance
- Radar Reconnaissance
- Ferret Reconnaissance

Support Activities and Experiments

- Human Factors
- Biomedical Factors
- General Scientific and Engineering Experiments

Subsystems

- Life-support (Atmospheric Considerations)
- Power Systems for MOL
- Electronic Subsystems
- Guidance and Attitude Control (Angular Motion Stability of a Satellite Telescope)
- Launch Vehicle

Simulation.

756. Institute of Radio Engineers, New York, New York, ADAPTIVE FLIGHT CONTROL, IRE Nat Aerospace Electronics Conference, Proceeding, 1962, pp. 644-701. "Capabilities and Limitations of Some Adaptive Techniques" by E. B. Stear and P. C. Gregory, pp. 644-660; "Guidance Theory and Extremal Fields" by H. J. Kelley, pp. 661-672; "Sampled-Data Adaptive Flight Control System with Incremental Computation" by H. Moreines, K. Moses, and A. Unger, pp. 673-688; and "Survey of Adaptive Methods for Bending Suppression in Large Boosters" by J. L. Box and J. C. Davis, pp. 689-701.

Not abstracted.

757. International Astronautical Federation, GENERAL GUIDANCE AND CONTROL CONCEPTS FOR SATELLITES AND SPACE VEHICLES by R. E. Roberson, August 1958, LAF Congress 9-0/184 (Unclassified).

The guidance and control for astronautical missions is discussed with emphasis on concepts and conceptual problems. Some of the requirements on the systems are presented including those of operational function, accuracy, reliability, weight, and environment. Present guidance and control status is reviewed in terms of guidance concepts and mechanization schemes with brief remarks on physical systems. Some problem areas worthy of immediate attention are listed.

758. Jacobi, W. J. and Bridge, C. S., FORMULATION OF GUIDANCE AND CONTROL EQUATIONS, THEIR MECHANIZATION AND INSTRUMENTATION, Braunschweig, Friedr. Vieweg and Sohn, 1962, pp. 93-101, (WGL Tagung, Freiburg im Breisgau, Germany, 10-13 October 1961, Wissenschaftliche Gesellschaft Für Luftfahrt, E. V., Jahrbuch, 1961, A63-21835).

Description of the derivation, mechanization, and instrumentation of guidance and control equations for a class of maneuverable, manned vehicles subjected to the following environment: altitude, 0 to 1,000,000 ft; velocity, 0 to 26,000 ft/sec; acceleration, ± 10 g; and time, up to three orbits. The problem is approached in three phases; preliminary examination, development of equations, and mechanization and system definition. The postulated system is described, and one possible mechanization is treated in detail.

759. Kang, G. and Kenehan, M. F.,
LONGITUDE POSITIONING AND ORBIT CONTROL OF THE 24-HOUR EQUATORIAL SATELLITE, AIAA Journal, Vol. 2, June 1964, pp. 991-999.

Not abstracted.

760. Kidd, A. T. and Soule, P. W.,
TERMINAL MANEUVERS FOR SATELLITE ASCENT RENDEZVOUS, ARS Journal, Vol. 32, January 1962, pp. 52-60.

Not abstracted.

761. Lessing, H. C., Tunnell, P. J., and Coate, R. E.,
LUNAR LANDING AND LONG-RANGE EARTH RE-ENTRY GUIDANCE BY APPLICATION OF PERTURBATION THEORY, Journal of Spacecraft and Rockets, Vol. 1, March - April 1964, pp. 191-196 (American Institute of Aeronautics and Astronautics, and NASA, 2nd Manned Space Flight Meeting, Dallas, Texas, 22-24 April 1963, pp. 140-150, A64-16642).

Not abstracted.

762. Levin, E.,
1964'S ASTRODYNAMICS, GUIDANCE, AND CONTROL CONFERENCE, Astronautics and Aeronautics, Vol. 3, No. 1, January 1965, pp. 66-68, 70.

Report on AIAA/ION Astrodynamics, Guidance, and Control Conference, 24-26 August 1964 at University of California, Los Angeles, where 30 papers were presented in six sessions; broad theme was vehicle motion, both motion of center of mass and motion about center of mass; vehicles considered included boosters, satellites, re-entry craft, and lunar-surface rovers; review of some papers relating to trajectory control, attitude control, and various space maneuvers.

763. Levine, G. M.,
APPLICATION OF MIDCOURSE GUIDANCE TECHNIQUE TO ORBIT DETERMINATION, AIAA Journal, Vol. 3, January 1965, pp. 137-139.

Not abstracted.

764. Lockheed-California Co., Burbank, California, MODULAR MULTIPURPOSE SPACE STATION STUDY. SECTION 3: MODULAR SPACE STATION DESIGN (2), FINAL REPORT, 30 July 1965, NASA-CR-65182, LR-18906, Vol. 3, CSCL22B, X66-11359, Contract NAS9-345 (Unclassified).

The subsystems, subsystem integration, and special subsystem studies are contained in this volume of a seven volume study on the modular multipurpose space station. Environmental control and life support; electric power; communications, command, and tracking; data management and displays; navigation and guidance; stabilization and control; and propulsion subsystems are included. Also, subsystems integration is considered for compartment arrangement; living quarters; and standarized compartment applications. The special subsystem studies include the effects of widely separated, nondirectional antennas on a rotating space station communications.

765. Lockheed-California Co., Burbank, California, SPACECRAFT GUIDANCE CONTROL AND RELATED TOPICS: A BIBLIOGRAPHY OF THE OPEN LITERATURE, JANUARY 1962 - JUNE 1963 by R. R. Scranton and A. A. Beltran, August 1963, LR-17100, N64-11412 (Unclassified).

The recent literature on navigation, guidance control, and reentry of spacecraft is presented in this unannotated bibliography. Emphasis has been placed on rendezvous, docking, energy management, and manual control.

766. Lockheed Missiles and Space Co., Sunnyvale, California, A PILOT DISPLAY CONCEPT FOR NEAR-TARGET MANEUVERS DURING RENDEZVOUS by D. W. Eliason and D. H. Utter, 1 March 1965, LMSC-6-65-65-3, N65-21539 (Unclassified).

A preliminary investigation was carried out for a translational control system concept for near-target maneuvers during rendezvous. The maneuvers are applicable to such missions as docking, inspection, and the Air Force Remote Maneuvering Unit. The concept consists of a small constant thrust acceleration directed at the target by the maneuvering vehicle, a phase-plane CRT representation of radar range and range rate with superimposed overlay contours, and a means for determining the appropriate scale factors for the phase-plane display in the general case. Translation is effected by suitable combinations of thrusting and nonthrusting periods. A pilot task description is given for a typical range change maneuver.

767. Lockheed Missiles and Space Co., Sunnyvale, California, A THEORETICAL METHOD FOR PRECISION RENDEZVOUS STATION-KEEPING by D. W. Eliason, 15 December 1964, LMSC-6-62-64-23 (Unclassified).

Not abstracted.

768. Lockheed Missiles and Space Co., Sunnyvale, California, DISCOVERER SUBSYSTEM D ENGINEERING ANALYSIS REPORT (SECOND REVISION) (U), July 1961, LMSC-446608-B, SSD-D-T61-38, AD-361 483L, Contract AF-04(647)-558 (Confidential).

Not abstracted.

769. Lockheed Missiles and Space Co., Sunnyvale California, ORBITAL DOCKING TEST STUDY (U), 11963, CR-50681, Report 2-11-61-1, X63-15086, Contract NAS8-864 (Confidential R/D).

Not abstracted.

770. Lockheed Missiles and Space Co., Sunnyvale, California, PROGRAM 461 VOLUME 2, TECHNICAL SUMMARY, VOLUME 2 (U), January 1963, SS-787-T63-2, Vol. 2, LMSC-BO58534-A, Vol. 2, AD-369 465, Contract AF-04(647)-787 (Secret).

Not abstracted.

771. Lockheed Missiles and Space Company, Sunnyvale, California, PROGRAM 622A SUBSYSTEM D ENGINEERING ANALYSIS REPORT, FINAL REVISION (U), July 1962, LMSC-446608-C, AD-363 142L, Contract AF-04(647)-673 (Confidential).

Not abstracted.

772. Markov, G. Yu. and Mikhaylov, F. A., RENDEZVOUS PROBLEM OF SPACE VEHICLE WITH ORBITAL STATION (Nekotoryye Voprosy Sblizheniya S Orbital'Noy Stantsiey) (Translated into English of a paper presented in the Intern. Federation of Autom. Control, Stavanger, Norway, 21-25 June 1965) (NASA-TT-F-9688, ST-CM-GC-10346, N65-33816, Contract NAS5-3760).

Considering that the various schemes of spacecraft rendezvous with orbital station consist of three stages, and that either of these stages consists in its turn of three phases, the present work is devoted to the problem of spacecraft guidance at long-range rendezvous phase with orbital station, utilizing the second derivative of the relative remoteness for information on line-of-sight rotation.

773. Martin Co.,
SPACE FLIGHT HANDBOOKS VOLUME I - ORBITAL FLIGHT HANDBOOK PART 3 - REQUIREMENTS, 1963, NASA SP 33, Pt.3, NAS8-5031 (Unclassified).

Not abstracted.

774. Mason, J. F. and Wolff, M. F.,
MISSILE AND SPACE ELECTRONICS; GUIDANCE AND CONTROL, Electronics, Vol. 34, 17 November 1961, pp. 94-99.

Not abstracted.

775. Massachusetts Institute of Technology, Instrumentation Laboratory, Cambridge, Massachusetts,
APOLLO GUIDANCE AND NAVIGATION - A UNIFIED EXPLICIT TECHNIQUE PERFORMING ORBITAL INSERTION, SOFT LANDING, AND RENDEZVOUS WITH A THROTTLEABLE ROCKET-PROPELLED SPACE VEHICLE by G. W. Cherry, August 1963, NAS9-153, NASA-CR-52557, R417, X64-10393 (Presented at the AIAA Guidance and Control Conference, Cambridge, Massachusetts, 13 August 1963) (Unclassified).

Not abstracted.

776. Massachusetts Institute of Technology, Instrumentation Laboratory, Cambridge, Massachusetts,
TECHNICAL DOCUMENTARY REPORT ADVANCED DEVELOPMENT PROGRAM (698CG) DEFINITION STUDY, VOLUME I, REPORT FOR 18 NOVEMBER 63-30 JUNE 1964 (U), June 1964, TDR-64 133, Vol. 1, AD-353 968, Contract AF-04(695)-490 (Secret).

Not abstracted.

777. McDonnell Aircraft Corporation, St. Louis, Missouri,
ORBITAL TESTING REQUIREMENTS FOR GUIDANCE AND CONTROL DEVICES, VOLUME II by F. Hercules and R. Butler, December 1965, NASA-CR-356, N66-14709, Contract NASw-1067 (Unclassified).

Technical descriptions for thirty candidate orbital experiments of piggyback guidance and control devices are presented. Experiments are divided according to the needs for orbital testing, development status, and dependence on carrier vehicle

design. Studies with devices that cannot adequately be ground tested include electrostatic gyro, low-g accelerometer, gravity gradient sensors, Earth horizon definitions, horizon sensor accuracy, gas bearings, and star characteristics. Experiments for the second group cover gravity gradient controls, ion attitude sensing, small impulse devices, optical mirrors and windows, etc. The last experiment category includes experiments on attitude control, master attitude reference, acquisition and tracking aids, time reference system, data handling system, command receiver, and electric power. All size, weight, and power estimates for experiment equipment were based on available packaging information.

778. Minor, J. W.,
LOW-COST STRAPDOWN INERTIAL SYSTEMS, New York, American Institute of Aeronautics and Astronautics, 1965, pp. 117-123 (AIAA/Ion Guidance and Control Conference, Mineapolis, Minnesota, 16-18 August 1965, A66-10001, A66-10015).

This article presents discussion of Honeywell's SIGN I (Strapdown Inertial Guidance and Navigation System) which is currently in test. The functional elements of the system are: three strapped-down gyros (GG87) operating in a pulse-on-demand rebalance mode, three strapped-down accelerometers (GG177) operating in a bang-bang pulse rebalance mode, pulse rebalance electronics for the gyro and accelerometer loops, a precision timing generator, and a DDA computer. The system has a volume of 550 in.^{3} and a weight of 30 lb; it uses 80 watts of power plus approximately 30 watts for a block heater and has a reliability of 3000 hr MTBF. The theory of operation is discussed, and techniques of gyro-pulse torquing rebalance and accelerometer-pulse rebalance are described. The applications of the system are expected to include orbital-injection, short-range-ballistic, space-station, and reentry missions.

779. Mitre Corporation, Bedford, Massachusetts,
A CRITICAL SURVEY OF IN-ORBIT GUIDANCE AND CONTROL PROBLEMS AND A FUNCTIONAL ANALYSIS OF A MASTER CONTROL CENTER by K. K. Maitra and G. A. Bakalyar, December 1963, TDR-63 482, AD-428 743, Contract AF-19 (628)-2390, N64-19813 (Unclassified).

Research is concerned with the in-orbit guidance and attitude control of space vehicles. The typical problems,

namely orbital transfer, rendezvous, interception, orbit sustaining, attitude control,and corrective guidance are discussed in a qualitative fashion. The significance of mass and/or time-optimized guidance,subject to important considerations such as boundedness of thrust magnitude, attitude and phase constraints, is emphasized. Precise mathematical formulations within the frameworks of the variational calculus followed by a brief critical survey of the available optimization techniques relevant to the above problems are also contained herein. The state-of-the-art and the available unclassified results are briefly reviewed. An analysis of the functional requirements of a control center relevant to in-orbit guidance is included.

780. Mitre Corporation, Bedford, Massachusetts, GENERAL ORBIT CHANGE OF AN EARTH SATELLITE BY A SINGLE IMPULSE by P. J. Plender, December 1963, TDR-63 481, AD-427 158, Contract AF-19(628)-2390 (Unclassified).

An analysis is presented of the mechanics and geometry of a general change in an Earth satellite orbit caused by a single impulse. Typical numerical solutions of the resulting equations, carried out by a digital computer program, are given.

781. Myers, G. H. and Thompson, T. H., GUIDANCE OF TIROS I., ARS Journal, Vol. 31, May 1961, pp. 636-640.

Not abstracted.

782. Perlmutter, L. D. and Carter, J. P., REFERENCE TRAJECTORY RE-ENTRY GUIDANCE WITHOUT PRELAUNCH DATA STORAGE, Journal of Spacecraft and Rockets, Vol. 2,November - December 1965, pp. 967-970 (American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 2nd, New York, New York, 25-27 January 1965, Paper 65-48, A66-12758).

Not abstracted.

783. Quasius, G. R.,
STRAPDOWN INERTIAL GUIDANCE, Space/Aeronautics, Vol. 40, August 1963, pp. 89-94 (A63-23010).

Consideration of the problems involved in using strapdown inertial guidance techniques, in which a space-stable reference frame is created within a computer, which also keeps track of the frame on the basis of rate measurements performed by body-fixed gyros. From the measurement axes fixed to the vehicle frame, a conversion to a space-stable frame is made by solving certain equations. The types of equations which must be solved are delineated, and methods for their solution, including the use of three types of digital mechanizations, are considered. Outlined is the use of a precession torque to eliminate the problems of precision power supplied, dwell time, and linearity involved in the rate-gyro method. Also outlined are precision encoders with high measurement response. The application of strapdown inertial guidance systems to ballistic missiles and to spacecraft designed for maneuvering during reentry is briefly considered.

784. National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama,
A STUDY OF ORBITAL DOCKING DYNAMICS by W. G. Thornton, X63-14566 (Intercenter Technology Conference on Control, Guidance, and Navigation Research for Manned Lunar Missions, Ames Research Center, 24-25 July 1962) (Unclassified).

Not abstracted.

785. National Aeronautics and Space Administration, Langley Research Center, Langley Station, Virginia,
A STUDY OF THE EFFECT OF A DEADBAND ABOUT A DESIRED PERIGEE ON THE GUIDANCE OF A SPACE VEHICLE APPROACHING THE EARTH by J. A. White, February 1963, NASA-TN-D-1607, N63-12592 (Unclassified).

A study has been made to determine the effect of using a deadband to account for instrumentation inaccuracies on the guidance of a space vehicle to a desired perigee altitude. Corrective impulses were applied when the predicted perigee altitude of the vehicle exceeded a boundary of a deadband assumed to exist about the desired perigee altitude.

786. National Aeronautics and Space Administration, Langley Station, Virginia,
LANGLEY RESEARCH CENTER SUMMARY OF RESEARCH APPLICABLE TO EARTH ORBIT RENDEZVOUS by R. F. Brissenden and J. E. Pennington, X63-14563 (Intercenter Technology Conference on Control, Guidance, and Navigation Research for Manned Lunar Missions, Ames Research Center, 24-25 July 1962) (Unclassified).

Not abstracted.

787. National Aeronautics and Space Administration, Washington, D. C.,
NASA GUIDANCE AND CONTROL by C. H. Gould, 1963, NASA-TM-X-51293, X64-10800 (Presented at the 1963 Northwest Electronics Research and Engineering Meeting, Boston, November 1963) (Unclassified).

Not abstracted.

788. Neufeld, M. J.,
ORBIT CORRECTION, Space/Aeronautics, Vol. 43, February 1965, pp. 48-55.

CONTENTS

Bibliography and diagram in addition to narrative.

789. Niemi, N. J.,
INVESTIGATION OF A TERMINAL GUIDANCE SYSTEM FOR A SATELLITE RENDEZVOUS, AIAA Journal, Vol. 1, February 1963, pp. 405-411.

Not abstracted.

790. Nita, M. M.,
A TRANSFER MANEUVER BETWEEN TWO NONCOPLANAR ELLIPTICAL ORBITS (Foreign title not available), Translated into English from Studii Si Cercetari De Mecanica Aplicata, Vol. 14, No. 3, pp. 5-3-589, 1963, by Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, March 1965, FTD-TT-64-1122, AD-460 499 (Unclassified).

This paper deals with a maneuver which allows the modification of the plane of an elliptical orbit, the form of the orbit

remaining unchanged. A constant ratio between the thrust and the satellite mass and an invariable space direction of the engine axis are considered. Under this hypothesis, results of a previous work are used to analyze a maneuver which permits uniformly circular motion in a plane which does not include the Earth's center O. Variation formulas for the final elements of the orbit are then given and it is shown that the maneuvering-plane orientation and engine thrust are functions of the initial orbit eccentricity. For each orbit with a given eccentricity, there are two possible types of maneuver. Extreme values of the final inclination of the orbit are finally established.

791. Ortusi, J.,
THE PRINCIPLE OF AUTOMATIC GUIDANCE OF LONG-RANGE ROCKETS AND SATELLITES. II. (Les Principes D'Auto-Guidage Des Engins A Grande Distance, Deuxieme Partie), Doc-Air-Espace, July 1963, pp. 17-34 (In French, A63-20891).

Review of the general principles of automatic inertial guidance systems. Briefly discussed are the theory and the two types of measuring gyroscopes. The following accelerometers are noted:

1) Standard nonintegrating accelerometers
2) Simply- and doubly-integrating accelerometers
3) Accelerometers with integrating Doppler effect.

Also considered are gravitational computations, including the choice of the system of coordinates and calculations of Earth gravitation. Defined are the reference geoid and ellipsoids. A comparison is made between automatic guidance and remote-control guidance of missiles.

792. Ostgaard, M. A., Stear, E. B., and Gregory, P. C.,
CASE FOR ADAPTIVE CONTROLS, AGARD-Report 406, July 1962, 25 pp.

This paper attempts to show that adaptive control systems are practical and represent significant advance over conventional linear control systems; typical flight control problem for reentry vehicles is outlined, conventional linear and adaptive solutions are discussed, and mechanization of adaptive flight control system for this application is described.

793. Pfeiffer, C. G.,
A DYNAMIC PROGRAMING ANALYSIS OF MULTIPLE GUIDANCE CORRECTIONS OF A TRAJECTORY, AIAA Journal, Vol. 3, September 1965, pp. 1674-1681 (A65-36472).

Treatment, from the dynamic programming point of view, of the problem of deciding when to apply guidance corrections to the perturbed trajectory of a spacecraft, where the objective of the guidance correction policy is to minimize the expected value of the squared error at the final time, subject to the constraint that the total-correction capability expended be less than some specified value. It is shown that this performance index is related to the probability that the final target error will lie within given limits. With certain constraints on the guidance policy, it is shown that a correction should be performed when a certain switching function passes through zero. Assuming that the orbit-determination procedure has been prespecified, and that the statistics of the correction errors are known, the switching function is found to depend upon the instantaneous state of the system, which is composed of the estimate of the trajectory perturbation to be corrected, the variance of the error in this estimate, and the correction capability of the spacecraft. Equations for computing the switching function are derived, and a numerical example is presented.

794. Powers, E. F.,
TIROS OPERATIONS, Astronautics and Aerospace Engineering, Vol. 1, April 1963, pp. 29-31.

Not abstracted.

795. Radio Corporation of America, Defense Electronic Products, Burlington, Massachusetts,
PROGRAM 706 TASK 5. GUIDANCE, TASKS 5.1.2.4.7.1 + 5.1.2.4.7.2 SHORT RANGE STATION KEEPING STUDIES, VOLUME II. FINAL REPORT (U), December 1963, TDR-63 397, AD-348 669, Contract AF-04 (695)-273 (Secret).

Not abstracted.

796. Romaine, O.,
GEMINI PROJECT REPORT, Space/Aeronautics, Vol. 38, October 1962, pp. 54-59.

Not abstracted.

797. Sanial, T. G.,
LONGITUDINAL MANEUVERS IN SUPERCIRCULAR RE-ENTRY, Astronautics and Aerospace Engineering, Vol. 1, December 1963, pp. 70-76.

Not abstracted.

798. Schirrmacher, K. H.,
SATELLITE AND SPACE VEHICLE CONTROL AND GUIDANCE PROBLEMS (Lenkungs- Und Steuerungsprobleme Von Satelliten Und Raumfahrtvehikeln), Translated into English from German by the Royal Aircraft Establishment, Farnborough, Hampshire, England, Braunschweig, Friedr. Vieweg and Sohn, 1962, pp. 85-93 (WGL Tagung, Freiburg im Breisgau, Germany, 10-13 October 1961, Wissenschaftliche Gesellschaft Für Luftfahrt E. V. Jahrbuch, 1961, A63-21834).

Discussion of the principles of guidance and control including a brief description of the radar and inertial guidance equipment. The need is stressed to treat the guidance problem as a system study of the complete loop including the behavior of the missile. It is shown that the general background knowledge for the consideration of guidance is provided by extensive performance studies optimizing on payload and suitable trajectories. The choice of the navigational part, either radar or inertial guidance, is discussed in terms of the general requirements; it is shown that a radar method, at least at present, provides lighter airborne equipment. The possibility of passive stabilization of Earth satellites in Earth axes is discussed by considering the dynamics of their motion. The difficulties of providing suitable reference systems for active stabilization are mentioned.

799. Schneider, A. M. and Capen, E. B.,
VARIABLE POINT GUIDANCE FOR SPACE MISSIONS,
American Institute of Aeronautics and Astronautics, and Institute of Navigation, Astrodynamics Guidance and Control Conference, Los Angeles, California, 24-26 August 1964, Paper 64-640, 40 pp. (A64-23823).

Discussion of a new guidance scheme for the control of a multistage rocket vehicle through the ascent phase of a complex space mission. Designed for the satellite rendezvous mission, variable point (VP) guidance is said to be extremely flexible and to be able to solve the guidance problem of many other space missions now being considered, including placement of a payload into a precise orbit of any kind, synchronous satellite, lunar impact, satellite rendezvous starting from orbit, orbit transfer, transfer from a general orbit to a particular desired orbital condition (such as for the start of reentry), space station resupply, and emergency satellite rescue. Among the subjects discussed are steering, thrust control, sequencing, launch windows, propellant consumption, computer implementation, and speed requirements. Appendices include a summary of equations used in variable point guidance, trajectory optimization and the two-point boundary-value problem, and disadvantages in the use of perturbation guidance for satellite rendezvous application. Definitions, a glossary, and a number of illustrations are presented.

800. Space Technology Laboratories,
APPLICATION OF LUNAR THEORY TO THE MOTION OF SATELLITES by P. Lanzano, January 1960, AAS Preprint 60-33 (Unclassified).

The Lunar Theory of Celestial Mechanics is applied to the problem of establishing a permanent artificial satellite on a periodic orbit around a planet. Using a method developed by C. L. Siegel, the Hill's equations of the Lunar Theory are solved to obtain the coordinates of the periodic trajectory as Fourier series of the time with respect to a rotating system reference. A recurrent procedure is obtained for evaluating the coefficient of the series in terms of the period of revolution. The Jacobi constant of the motion is also expressed as an infinite power series of the period. The convergence of such expansions can be ascertained for small values of the period.

801. Sperry Rand Corporation, Sperry Gyroscope Co., Great Neck, New York,
ORBITAL LAUNCH OPERATIONS VOLUME I - SUMMARY, January 1962, AB-1210-0004-1 (Unclassified).

This volume summarizes the investigations which have been made toward conducting orbital launch operations. Considered as separate problems, and summarized in this volume, are studies on communications and telemetry navigation, guidance, and rendezvous attitude control computer requirements and applications, automatic checkout equipment, and secondary power.

802. Sperry Rand Corporation, Sperry Gyroscope Co., Great Neck, New York,
ORBITAL LAUNCH OPERATIONS, VOLUME III-NAVIGATION, GUIDANCE, AND RENDEZVOUS, January 1962, AB-1210-0004-3 (Unclassified).

The major astrionic requirements for orbital launch operations are being investigated. This volume covers the studies which have been made on navigation, guidance, and rendezvous for this program.

803. Steffan, K. F.,
SATELLITE RENDEZVOUS TERMINAL GUIDANCE SYSTEM, ARS Journal, Vol. 31, November 1961, pp. 1516-1521.

Not abstracted.

804. TRW Space Technology Laboratories, Redondo Beach, California.
RENDEZVOUS AND ORBITAL DOCKING: A BIBLIOGRAPHY (U) by J. F. Price and A. K. Dunlap, April 1963, AD-413 432 (Unclassified).

This bibliography consists of 369 references on rendezvous and orbital docking studies covering manned and unmanned rendezvous as well as some references on satellite interception. The majority of the references are those published during the period January 1958 to March 1963. The abstracts contained in this bibliography are primarily those written by the individual authors. If an author does not include an abstract with his paper, one is prepared by the compiler from the text of his report using the authors words. If this is impractical, a brief summary statement or table of contents is provided. Author,

agency, serials, subject, ASTIA documents, and NASA documents indices are included.

805. Vaccaro, R. J. and Kirby, M. J.,
RENDEZVOUS GUIDANCE OF LIFTING AEROSPACE VEHICLES, American Institute of Aeronautics and Astronautics, Annual Meeting, 1st, Washington, D. C., 29 June - 2 July 1964, Paper 64-241, 11 pp. (A64-20142).

Description of an explicit guidance system which would allow a lifting vehicle to enter a rendezvous target's orbit plane and ascend in this plane. In this scheme, the place and time of the rendezvous are not specified. Instead, only the destination orbit and the phase of the moving target in this orbit are specified. The scheme consists of ascent and out-of-plane guidance equations which operate in parallel to define the vehicle's path. These equations are derived and discussed. The out-of-plane guidance operates to bring the vehicle into the plane of ascent and align it before the thrust cutoff. The ascent guidance defines an ascent path to a cutoff which will place the vehicle in a coasting path to meet the target. An atmospheric form of crossproduct steering permits explicit guidance to begin while the vehicle is still within the detectable atmosphere.

806. Valley Forge Space Technology Center, Philadelphia, Pennsylvania,
UNTITLED, REPORT FOR 1 JUNE - 30 SEPTEMBER 1964 (U), September 1964, TR-64 221, AD-353 827, Contract AF-04 (695)-559 (Secret).

Not abstracted.

807. Vester, B. H.,
GEMINI RENDEZVOUS RADAR, Westinghouse Engineering, Vol. 24, January 1964, pp. 19-23.

Not abstracted.

808. Ward, J. W. and Williams, H. M.,
ORBITAL DOCKING DYNAMICS, AIAA Journal, Vol. 1, June 1963, pp. 1360-1364.

Not abstracted.

809. Webb, J. A.,
GUIDANCE AND DATA TRANSMISSION CONSIDERATIONS FOR A LUNAR MAPPING SATELLITE, Communications and Electronics, September 1962, pp. 225-229.

Not abstracted.

810. Western Electric Co., Inc., New York, New York,
COMMAND GUIDANCE SYSTEM, DELTA 7, TIROS D FLIGHT TEST REPORT (U) by K. R. Carpenter, March 1962, AD-359 329, Contract AF-04(645)-5 (Confidential).

Not abstracted.

811. Western Electric Co., Inc., New York, New York,
WS 107A-2 RADIO-INERTIAL GUIDANCE SYSTEM FLIGHT TEST REPORT DELTA 6, S-3, EXPLORER XII (U) by K. R. Carpenter, September 1961, AD-359 330, Contract AF-04 (645)-5 (Confidential).

Not abstracted.

812. Westinghouse Electric Corporation, Baltimore, Maryland,
GROUND-BASED NAVIGUIDANCE TECHNIQUES FOR RECONNAISSANCE SATELLITES QUARTERLY TECHNICAL REPORT NO. 1, 1 APRIL - 1 JULY 1963 (U), December 1963, TDR-63 348, AD-347 359, Contract AF-30(602)-3022 (Secret).

Results of the first quarter of the study are summarized and the status at that point is given. Detailed results of two work tasks on environment effects and satellite considerations are included as appendices. The first task covers atmospheric attenuation and refraction, physical environment, natural noise sources, and man-made interference. The second task includes satellite maneuvers, orbital perturbations, station coverage time, and the equations describing maneuvers and their errors.

813. Xydis, F. E.,
DESIGNING LONG-LIFE UNMANNED SATELLITES, Aerospace Engineering, Vol. 21, September 1962, pp. 84-85.

Not abstracted.

814. Air Force Systems Command, Electronic Systems Division, Bedford, Massachusetts,
A SUMMARY OF CONFIGURATION DESIGN STUDIES FOR A RANGE INSTRUMENTATION CALIBRATION SATELLITE (U) by J. J. Blum, TDR-64 255, AD-439 358, (Unclassified).

The results are summarized of five separate but related analytical investigations into the engineering design of a calibration satellite. The suitability and adaptability of the Mistram, Glotrac, and AN/DPN-66 C-Band Radar Transponders, and Xenon Flash Optical Beacon, for use in a proposed calibration satellite is discussed. The overall results of a separate satellite integration study are likewise presented. Design specifications have been developed which allow initiation of transponder development. The electronic transponders required in a calibration satellite can be developed essentially from existing missile-rated designs.

815. Andreyev, V. D.,
ERRORS IN INERTIAL NAVIGATION SYSTEMS, Engineering Cybernetics (USA), No. 2, 1964, pp. 131-144.

This is the fifth of a series of publications by the author and is based on equations derived by V. D. Andreyev (theory of inertial systems of autonomic determination of the coordinates of a moving object, Priklad. Mat. Mekh. (USSR), Vol. 28, No. 1, 39, 1964). Solutions to the second order simultaneous differential equations are derived for four cases of orbital motion, of increasing interest, for which equations with constant coefficients can be constructed. For the case of motion with constant velocity along a parallel path, non-asymptotic Lyapunov stability is shown and two approximate simplified solutions obtained in a restricted case. Expressions of the same form but with additional terms are derived in the complete case. Previous translation and errors make the paper difficult to read.

816. Army Missile Command, Redstone Arsenal, Alabama,
STAR IDENTIFICATION FOR BALLISTIC MISSILERY by C. C. Sherman, 24 June 1964, RT-TM-64-33 (Unclassified).

This report states the conditions under which stars must be used. It explains the equipment needed for star identification.

The field operation is outlined and procedure in star identification is shown. Film reading and the electronic computing are explained. There is a glossary of terms and abbreviations.

817. Avrech, N.,
USE OF THE EARTH'S MAGNETIC FIELD FOR NAVIGATION AND ATTITUDE CONTROL, Proceedings of the Institutions of Radio Engineers (USA), Vol. 50, No. 4 (I), April 1962, 485 pp.

If future measurements show that the shape of the magnetic equator is relatively constant at the altitudes of satellites even in the presence of magnetic storms it should be possible to design a self-contained navigation system of sufficient accuracy for many purposes based on accumulated clock times of crossings of the magnetic equator. Navigational fixes would be obtained at magnetic equator crossings, thereby eliminating accumulative errors. The principle may also be applied to attitude control of a satellite by utilizing the interaction between the Earth's magnetic field and a magnetic moment generated inside the satellite. Brief details of possible systems are described.

818. Bos, H. J.,
SATELLITE-NAVIGATION, TRANSIT-SECOR, Technisch Documentatie en Informatie Centrum voor de Krijgsmacht, The Hague (Netherlands), October 1965, 84 pp. (TDCK-43209, N66-19181).

The bibliography contains a literature survey, comprising 125 abstracts of articles, published papers, and reports on the subject of satellite navigation, navigational satellites, and geodetic satellites. The available material is presented chronologically in six chapters. A historical review and a summary of technical details is included.

819. Burke, W. F.,
GEMINI NAVIGATION CONSIDERATIONS, Washington, Institute of Navigation, 1965, pp. 1-26 (In: Navigation for Manned Space Flight, 1964, Space Navigation Conference, St. Petersburg, Florida, 30 April and 1 May 1964) (A66-11314 A66-11315).

Description of the six distinct regimes presenting significantly different navigation problems, viz., launch vehicle standby guidance, post insertion orbit correction, catch-up

maneuvers, rendezvous terminal guidance, orbit navigation, and reentry guidance. The spacecraft configuration is sufficiently described to permit separation of the control-guidance functions and the navigation functions. The energy versus navigation constraints are discussed, and rules-of-thumb are advanced which permit technical management to approximate the tradeoffs involved for various velocity-gain profiles involved in small increments of orbital adjustments and rendezvous maneuvers for vehicles in nearly-circular, near-Earth orbits. The mathematical background and validation for these rules-of-thumb, useful in making preliminary management judgements, are presented.

820. Clegg, J. E.,
THE NAVIGATION OF A COMMUNICATION SATELLITE,
J. Inst. Navig. (GB), Vol. 16, No. 2, April 1963, pp. 163-179.

The navigational aspects of the requirements for a medium altitude satellite communication system are discussed. Twelve satellites have to be injected into a circular equatorial orbit with very great precision. It is not practicable to navigate the launching vehicle accurately enough to obtain the correct orbit at first injection and the satellite itself has to be controlled and adjusted until finally it is correctly positioned with the right period. The navigation of the third-stage rocket is discussed as this affects the limits of adjustment required for the satellite. Some error in period is necessary at injection to position the satellite correctly in orbit in a reasonable time. A suitable tolerance on the period at injection is three minutes in eight hours. This must be reduced by fine adjustment of the satellite speed to less than 30 milliseconds. Methods of measuring the orbital period to this curacy are discussed. When the 12 satellites are finally in rbit and equally spaced around the orbit they should remain for up to five years with the pattern substantially undisturbed. This paper was presented at an ordinary meeting of the Institute held in London on 18 January.

821. Emmerich, C. L.,
APPLICATION OF FLOATED GYROS IN GUIDED MISSILES AND SPACE VEHICLES (ANWENDUNG DER SCHWIMMKREISEL BEI LENKGESCHOSSEN UND IN DER RAUMFAHRT) Translated into English from German by the United Aircraft Corporation, Norden Division, Norwalk, Connecticut, WGL Tagung, Freiburg im Breisgau, Germany, 10-13 October 1961, (In: Wissenschaftliche Gesellschaft für Luftfahrt E. V. Jahrbuch, 1961) (Brunschweig, Friedr. Vieweg and Sohn, 1962, pp. 319-322, A63-21864).

This article presents a comparison of the conditions for the application of floated gyros, nonfloated gyros, manned telescopes, and electronic startrackers. It is shown that floated gyros exhibit the best performance in flight in the vicinity of Earth or other planets. A small all-attitudes inertial platform is described in which floated gyros are used as the primary guidance components. Recent advances in the art of precision angle pickoff design and in the miniaturization of electronic control amplifiers are discussed.

822. Freiesleben, H. C.
NAVIGATIONAL AID FROM OTHER SATELLITES, J. Inst. Navig. (GB), Vol. 15, No. 2, April 1962, pp. 149-154.

Besides measuring changes of distance by means of the Doppler effect on frequencies transmitted by a satellite, it is possible to observe altitudes and azimuths or the rates of change of these quantities. Advantages and disadvantages of such observations are compared with the Transit program: the formulae for position lines determined by rates of change of altitude and azimuth are derived and discussed. Measurements of distance, at present feasible only by radar, may be possible in the future by comparison of atomic clocks; the evaluation is simpler than for all other observations of satellites.

823. Gabloffsky, H.,
A SUN-VECTOR REFERENCED EARTH-SATELLITE GUIDANCE SCHEME. APPENDIX - YAW ERROR OF THE SUN POSITION INDICATOR AS A FUNCTION OF ATTITUDE MISALIGNMENT, 1962 IRE International Convention Record, Part 5 - Aerospace and Navigational Electronics; Military Electronics; Radio Frequency Interference; Space Electronics and Telemetry, Vol. 10, pp. 105-136 (Institute of Radio Engineers, International Convention, New York, New York, 26-29 March 1962, A63-12525).

Presentation of a new guidance scheme which uses tandem sun-position indicators with digital, two-axis, directional readouts to stabilize the vehicle in reference to a rotating-vehicle-centered coordinate system. Two such sun-seekers provide detection about the complete sphere. The system is shown to be suitable for the three guidance modes of yaw sensing, velocity sensing, tumble measurements, and general vehicle-attitude sensing. The sun-seekers can be used in conjunction with other sensors, or alone. To establish vehicle orientation and position, the time-related precomputed components of the sun-vector are stored in the satellite for comparison with measured values from the sun-position indicators. The differences between the measured and stored data are used in the control loop to indicate attitude corrections.

824. General Electric Co., Johnson City, New York,
A STUDY OF THE USE OF REDUNDANT INFORMATION ON SPACE GUIDANCE SYSTEMS TO ACHIEVE MALFUNCTION DETECTION AND CONTROL, FINAL REPORT, 15 JUNE 1963-15 JANUARY 1964 by H. B. Haake, R. O. McCary, R. Rapacz, G. T. Sendzuk, and G. K. Smith, April 1964, TDR-64-60, AD-436 110, Contract AF-33(657)-11654 (Unclassified).

A theoretical orbital navigation system was synthesized that employs techniques for achieving a high degree of reliability through the application of redundant equipment and malfunction detection capability. Malfunction detection is used to implement standby redundancy, or to reorganize the system to permit continued operation, with fewer sensors, subsequent to measurement subsystem failures. The latter case results in progressive performance degradation. The resulting potential modes of operation are defined, and the level of performance, in terms of orbit determination accuracy, has been evaluated

for each. The mission assumed was to provide for attitude control and guidance for relatively infrequent orbital maneuvers for an unmanned satellite surveillance unmanned mission has precluded the use of manual repair techniques The reliability goal has been to achieve a system capable of a 40,000 hour equivalent mean time to failure for a 10,000 hour mission, with a growth capability to 270,000 hours equivalent mean-time to failure.

825. Graham, G. E.
FINE POINTING CONTROL FOR THE ORBITING ASTRONOMICAL OBSERVATORY (OAO), North Hollywood, California, Western Periodicals Co., 1963, pp. 1.5.2-1 - 1.5.2-5, Conference sponsored by the Baltimore Section of the Institute of Electrical and Electronics Engineers and the Professional Technical Group on Aerospace and Navigational Electronics, 10th, Baltimore, Maryland, 21-23 October, Proceedings, A64-18279).

Discussion of the high pointing accuracy requirements imposed on the control system of the OAO. It is stated that 0.1-arcsecond angular accuracy can be achieved in orbiting spacecraft using star references.

826. Kershner, R. B. and Newton, R. R.,
THE TRANSIT SYSTEM, J. Inst. Navig. (GB), Vol. 15, No. 2, April 1962, pp. 129-144.

The Transit navigational satellite system is expected to be in operational use during the second half of 1962, though not perhaps with its full quota of four satellites. The system, which will be of considerable significance to both air and surface navigation, is described. Using a single of the two frequencies transmitted by the satellite, the mean navigation error is about one mile, limited by refraction. Using both frequencies the mean error is about one-half mile, limited by the accuracy of the satellite coordinates that are transmitted. With elaborate equipment, it is possible to navigate to about 0.1 mile, although the satellite coordinates that are available to the ordinary user do not reflect this full accuracy. When all four satellites are in orbit, a fix will be available every 110 minutes, on the average, with occasional intervals of 220 minutes between fixes.

827. Levine, G. M.,
A METHOD OF ORBITAL NAVIGATION USING OPTICAL SIGHTING TO UNKNOWN LANDMARKS, New York, American Institute of Aeronautics and Astronautics, 1965, pp. 248-255 (In: AIAA/Ion Guidance and Control Conference, Minneapolis, Minnesota, 16-18 August 1965, A66-10001, A66-10025).

Discussion of the method of recursive space navigation and its application to navigating in a near orbit of a planet by means of measuring the directions to known landmarks. A less restrictive method of recursive orbital navigation in which it is not necessary to identify the landmarks is presented. Navigational data are obtained from two optical sightings to the same unknown landmark. The position of the landmark and the two points from which the sightings are made determine a plane. At one position (the normal point) between the two sighting points, the velocity vector of the spacecraft has no component perpendicular to the plane. The location of the normal point is obtained as a function of the two sighting points only and is independent of both the path between the two points and the location of the landmark. The unknown-landmark orbital navigation procedure is then constructed from these results. Computer simulation results of the use of this method for both Earth and lunar orbital navigation are presented.

828. Lillestrand, R. L. and Carroll, J. E.,
HORIZON-BASED SATELLITE NAVIGATION SYSTEMS, IEEE Transation Aerospace Navigation Electronics (USA), Vol. ANE-10, No. 3, September 1963, pp. 247-270.

The Earth's horizon provides an important and conspicuous basis for the development of self-contained systems for Earth-satellite navigation. The present paper investigates horizon-based navigational systems in which the requirement for vehicular yaw stabilization is not imposed. This permits the development of a variety of navigational techniques which generally fall within one of the following divisions: star matching, stellar almucantar transits, limb occulations, surface almucantar transits, and map matching. By measuring time directly, the raw data are immediately available for digital processing. Error contributing factors such as the aspherical shape of the Earth and the seasonal and latitudinal variation of the atmospheric density profile can be largely eliminated by introducing suitable corrections. Furthermore, heavy reliance can be placed on the digital computer for star identification and

for the introduction of these various correction terms. As a result, these techniques have the virtue of requiring only the simplest of navigational equipment. They yield Earth-satellite position fixes with potential accuracies in the range from 1 to 10 miles.

829. Massachusetts Institute of Technology, Instrumentation Laboratory, Cambridge, Massachusetts,
CAMBRIDGE APOLLO GUIDANCE AND NAVIGATION - APPLICATION OF MIDCOURSE GUIDANCE TECHNIQUE TO ORBIT DETERMINATION by G. M. Levine, December 1962, X63-12317, Contract NAS9-153 (Unclassified).

Not abstracted.

830. Massachusetts Institute of Technology, Instrumentation Laboratory, Cambridge, Massachusetts,
UNTITLED, INTERIM TECHNICAL DOCUMENTARY REPORT (U) by E. G. Ogletree, September 1963, AD-346 918, Contract AF-04(695)-289 (Confidential).

Not abstracted.

831. Massachusetts Institute of Technology, Lincoln Laboratory,
HAYSTACK POINTING SYSTEM: BELT by A. A. Mathiasen, 9 September 1965, TN-1965-37, Contract AF-19(628)-5167 (Unclassified).

Not abstracted.

832. Massachusetts Institute of Technology, Lincoln Laboratory,
HAYSTACK POINTING SYSTEM: STARS by H. E. Frachtman, 25 September 1964, Gp 1964-47, Contract AF-19(628)-500 (Unclassified).

This report describes the procedure used by the Haystack pointing computer program for obtaining the celestial coordinates of the stars at any time.

833. Massachusetts Institute of Technology, Lincoln Laboratory,
HAYSTACK POINTING SYSTEM: SUN by H. E. Frachtman, 29 July 1964, Gp 1964-40, Contract AF-19(628)-500 (Unclassified).

SUNTRACK is a program in the Haystack Univac 490 pointing system whose output is the celestial coordinates of

the sun at a given time. The program computes the coordinates by third difference into polation in the tables of the apparent light ascension, declination, and radium vector of the sun published in The American Ephemeris.

834. National Aeronautics and Space Administration,
THE EFFECT OF LATERAL- AND LONGITUDINAL-RANGE CONTROL ON ALLOWABLE ENTRY CONDITIONS FOR A POINT RETURN FROM SPACE by A. G. Boissevain, July 1961, TN D-1067 (Unclassified).

The problem of return to a specified landing point on the Earth from space is considered by studying the interaction between an assumed representative control over the lateral and longitudinal range and the initial conditions of approach to the Earth. Lateral ranges of ±500 miles are shown to allow tolerances in time of return of up to 3-½ hours or tolerances in orbital-plane inclination of up to 13 degrees.

835. National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Maryland,
MATHEMATICAL ANALYSIS FOR THE ORIENTATION AND CONTROL OF THE ORBITING ASTRONOMICAL OBSERVATORY SATELLITE by P. B. Davenport, January 1963, NASA TN D-1668, N63-12063 (Unclassified).

A mathematical model is developed by which the following satellite orientation and control problems may be resolved:

1) Determining attitude for maximum area of solar cells in sunlight.
2) Generating slewing commands for a change in attitude.
3) Computing startracker gimbal angles for maintaining proper orientation and for determining when guide stars are occulted by the Earth, Sun, and Moon.

836. National Aeronautics and Space Administration, Langley Station, Virginia,
LANGLEY RESEARCH CENTER ACCURACY OF POSITION FIXING AND ORBIT DETERMINATION FROM VARIOUS OPTICAL MEASUREMENTS MADE ONBOARD A CIRCUMLUNAR VEHICLE by A. P. Mayo and H. A. Hamer, X63-14570, (Intercenter Technology Conference on Control, Guidance, and Navigation Research for Manned Lunar Missions, Ames Research Center, 24-25 July 1962) (Unclassified).

Not abstracted.

837. National Aeronautics and Space Administration, Washington, D. C.
INTERPLANETARY EXPLORER SATELLITES, 1964, N64-28711 (NASA Facts, Vol. 11, No. 1) (Unclassified).

Basic facts are presented about the interplanetary Explorer series of satellites, the first of which, Explorer XVIII, was launched 26 November 1963. These satellites are aimed primarily at acquiring additional knowledge about radiation and magnetic fields in space between the Earth and moon during a major part of the solar cycle. A description of Explorer XVIII, its communications and power system, orbital information, and tracking by the new Satellite Tracking and Data Acquisition Network (STADAN) is included. Preliminary analyses of data from Explorer XVIII have provided significant information about a shock wave that envelops the Earth, and about a band of radiation lying above the Van Allen region.

838. Naval Ordnance Test Station,
SEMINAR LECTURES ON CELESTIAL MECHANICS, 27 May 1958, NOTS 2040 (Unclassified).

This report is a transcription of the following 10 lectures:

1) "Fundamental Principles of Celestial Mechanics" by R. H. Olds.
2) "Rectilinear Motion" by E. B. Mayfield.
3) "Central Forces" by A. J. Jaske.
4) "Attraction of Bodies" by W. A. Allen.
5) "Planetary Motion (Problem of two Bodies)" by W. F. Koehler.
6) "Optimum Launching Altitude for a Satellite" by A. Hibbs.
7) "Geophysical Perturbations of an Earth Satellite" by L. Blitzer.
8) "Astronomical Coordinate Systems" by P. St. Amand.
9) "Perturbations" by R. B. Leipnik.
10) "Determination of Orbits" by W. C. White.

839. North American Aviation Inc., Downey, California,
MANNED ORBITAL SPACE STATION TECHNICAL SUMMARY-VOL. 1, February 1963, NAS1-1630, AD-402 489L (Unclassified).

Not abstracted.

840. Payne, S.
HEAT, SUN, AND STARS TO POINT SATELLITE PAYLOADS, Control Engineering, Vol. 8, October 1961, pp. 22-24.

Not abstracted.

841. Polack, P.
EXAMPLES OF APPLICATIONS OF RECURSIVE NAVIGATION (Examples D'Applications Des Procedes De Navigation Recursive), International Astronautical Federation, International Astronautical Congress, 16th, Athens, Greece, 13-18 September 1965, Paper, 14 pp. (A66-15912, In French).

Theoretical analysis of the principles upon which recursive navigation is based followed by two specific examples to which this technique is applied. The sum total of observable magnitudes are associated with components of a vector known as the measurement vector. The components of the perturbation vector are next considered and it is assumed that the perturbations can be described from the statistical viewpoint using autocorrelation functions. It is shown that there are two basic phenomena which affect the generation of errors of estimation - transition and degradation. Transition is due to intrinsic errors in measurement, while degradation refers to the existence of unknown perturbing terms. The recursive method is applied to the ELDO satellite and to a hypothetical orbiting body.

842. Radio Corporation of America, Defense Electronics Products, Princeton, New Jersey,
RANGE CALIBRATION SATELLITE PRELIMINARY DESIGN REPORT, REPORT FOR 24 JUNE-31 OCTOBER 1963, October 1963, AD-442 742, Contract AF-19(628)-3260 (Unclassified).

The Range Calibration Satellite (RCS) is a 300-pound spacecraft which will be used as a calibration tool for range instrumentation equipment. For the calibration mission, the

spacecraft carries a mistram, a glotrac, and a DPN-66 transponder and an optical beacon. The flash from the optical beacon can be photographed against a stellar background. The range calibration satellite will be launched into a nominally circular 400-nautical-mile orbit by the THOR-DELTA launch vehicle. The 40-degree-orbit inclination has been selected to satisfy the requirements of the worldwide electronic tracking stations. A detailed preliminary design has established that an adaption of the RCA TIROS meteorological satellite will fulfill calibration satellite specifications. This harmony of the RCS design with the mission requirements includes established compatibility with the THOR-DELTA launch craft and space-proven thermal and power supply designs. In addition to the TIROS configuration, many components and instrumentation techniques used on the TIROS spacecraft can be used in the RCS with only minor modification.

843. Rath, H. L.
ELECTRICAL EQUIPMENT OF NAVIGATION SATELLITES AND ASSOCIATED EARTH STATIONS, Electron. Rundschau (Germany), Vol. 15, No. 10, October 1961, pp. 461-466 (In German).

Introduction to methods of navigation permitting to take a bearing independently of weather conditions and of the instantaneous position. After a brief explanation of the radio sextant, the equipment of the Transit System is discussed. Described are methods to eliminate the effect of the ionosphere, and to separate the signal from noise, as well as the method of transmitting satellite-orbit data and time signals to observers.

844. Spencer, D. F.
NAVIGATION IN SPACE ELECTRONICS, IEEE Internat. Convention Record (USA), Vol. 13, Pt.4, 1965, pp. 108-111.

This article discusses the background of the U.S. Department of Defense present navigational programs, explores many of the considerations involved in establishing new navigation requirements, and describes system characteristics such as satellites which could be developed to meet these requirements.

845. Wilcox, J. C.,
SELF-CONTAINED ORBITAL NAVIGATION SYSTEMS WITH CORRELATED MEASUREMENT ERRORS, New York, American Institute of Aeronautics and Astronautics, 1965, pp. 231-247, Contract AF-04(695)-526 (In: AIAA/ION Guidance and Control Conference, Minneapolis, Minnesota, 16-18 August 1965, A66-10001, A66-10024).

Analysis of a self-contained orbital navigation system using Earth-horizon measurements in the 14-16μ carbon dioxide absorption band, using Kalman's linear filter theory. The spatial correlation of the horizon height deviations is converted into time correlation of the sensor measurement errors. The orbital dynamics, horizon phenomenology, and the horizon tracker, startracker, radar altimeter, and inertial-measurement-unit instrument errors are represented by linearized differential equations in the Kalman canonical form. A generalized error analysis computer program is used to perform the calculations. The results demonstrate that high sampling rates, which produce marked improvement in performance in the presence of uncorrelated errors, are of no value for reducing the effects of correlated errors. The system performance as a function of time is presented for different values of the error sources. The efficacy of a radar altimeter in reducing the inplane navigation error, especially during the initial transient, is shown.

3. Attitude Control (Stabilization)

846. Aerojet-General Corporation, Azusa, California,
FABRICATION AND LAUNCH OF ABLESTAR STAGES FOR PROJECT TRANSIT/ANNA LETTER PROGRAM PROGRESS REPORT NO. 18 (U) by F. J. Gavlin, July 1962, L-5285-01-18, AD-364 347, Contract AF-04(695)-17 (Confidential).

Not abstracted.

847. Aeronautical Systems Division,
TECHNIQUES FOR ANALYSIS OF NONLINEAR ATTITUDE CONTROL SYSTEMS FOR SPACE VEHICLES. VOLUME II - TECHNIQUES FOR ANALYSIS AND SYNTHESIS OF NON-LINEAR CONTROL SYSTEMS by E. I. Ergin, June 1962, ASD-TDR-62-208, AD-282 805, Contract AF-33(616)-7811 (Unclassified).

This report was prepared to compile the available non-linear analysis and design techniques for space vehicle attitude control systems. Volume II treats in detail the principal techniques for the analysis of nonlinear control systems and shows the application of them to specific attitude control problems.

848. Aeronautical Systems Division, Dir/Aeromechanics, Flight Control Laboratory, Wright-Patterson Air Force Base, Ohio,
TECHNIQUES FOR ANALYSIS OF NONLINEAR ATTITUDE CONTROL SYSTEMS FOR SPACE VEHICLES, VOLUME IV, FINAL REPORT by E. I. Ergin, V. D. Norum, and T. G. Windeknecht, June 1962, ASD-TDR-62-208 (Unclassified).

This four volume report was prepared to compile, describe, and apply the available nonlinear analysis and design techniques for space vehicle attitude control systems and to outline additional areas of future effort to improve present analysis and design procedures. Each of the four volumes is relatively independent of the others. Volume I is a definition and description of the problems associated with the design of the space vehicle attitude control systems. Volume II treats in detail the principal techniques for the analysis of nonlinear control systems and shows the application of these techniques to specific attitude control system problems. Volume III discusses three general problems in space vehicle attitude control systems: single axis on-off gas jet system design, active attitude control system design for a spin-stabilized vehicle, and the design of a control system for a satellite vehicle with reaction wheels and gas jets. Volume IV is a collection of references and a bibliography with annotations and comments covering the spectrum of the study effort.

849. Aeronutronic,
A GENERAL PERTURBATIONS DIFFERENTIAL CORRECTION PROGRAM by J. L. Arsenault, 1 August 1963, Aeronutronic Pub U-2201, AD-419 144, Contract AF-19(628)-562 (Unclassified).

An experimental computer program is described, which calculates Earth satellite ephemerides, corrects orbit elements, and evaluates the effects of various terms of the bulge perturbation theory. Formulation, flow charts, input formats, and sample cases are given.

850. Aerospace Corporation, El Segundo, California,
A NEW METHOD OF ATTITUDE STABILIZATION by A. S. Gutman, January 1964, TDR-269 4513, TDR-63 358, AD-432 841, Contract AF-04(695)-269 (Unclassified).

The basic purpose of stabilization to beam radiation into a definite direction is combined with the stabilization system by means of a stabilized reflector. A spin-stabilized satellite is magnetically or electrostatically suspended on a gravity-gradient stabilized reflector. The reflector serves to direct the radiation emanating axially from the spin-stabilized satellite toward the Earth. This concept is demonstrated on a communications satellite and on a surveillance satellite in which the spin motion of the satellite is used to generate a continuous circular scan on the surface of the Earth. The dynamics of a satellite combining spin-stabilization with gravity-gradient stabilization by a vertistat are analyzed. The equation of attitude motion is derived and solutions for the motion of the vertistat with reference to the local vertical are obtained. The frequency of vibration of the satellite under disturbing forces is found to be a design constant of the system. Since it is possible to design for a high constant frequency of vibration in the roll and yaw axis vibrations, damping by means of a tuned damper can be achieved effectively and quickly. For the pitch axis vibration, an active damping by one cold gas pulse jet is proposed. The same pulse jet can be used to compensate for angular spin velocity decay and also for station-keeping or orbit period control.

851. Aerospace Corporation, El Segundo, California, ELECTRONICS PROGRAM, SATELLITE ATTITUDE CONTROL SYSTEM EXPERIMENTS SEMIANNUAL TECHNICAL REPORT, 1 JANUARY - 30 JUNE 1963 by D. J. Griep and J. G. Zaremba, October 1963, TDR-63 228, AD-423 888 (Unclassified).

Primary effort was devoted to the evaluation and initial operation of the single axis, wire supported, space-vehicle simulator. A bang-bang attitude control system was implemented to aid in the evaluation of the simulator and a new draftfree enclosure was constructed to house the simulator. Two pieces of special purpose test equipment, a sun sensor and a light source, were designed and fabricated. An integrated power system, designed for the simulator, is in the process of implementation. Implementation of the attitude control system was initiated. The horizon-sensing system was qualitatively evaluated, and a derived-rate controller was mechanized and operated.

852. Aerospace Corporation, Los Angeles, California, ADVENT PROGRAM, STATUS REPORT 16 JANUARY - 15 FEBRUARY 1962 (U), February 1962, CSR-930(2109) MPR-8, AD-358 388, Contract AF-04(647)-930 (Confidential).

Not abstracted.

853. Aerospace Corporation, Los Angeles, California, EQUATIONS OF MOTION FOR A GRAVITY-GRADIENT STABILIZED SATELLITE SUBJECT TO AMBIENT PERTURBING FORCES AND TORQUES by V. Chobotov, May 1964, TDR-269 (4540-70)-2, TDR-64 114, AD-605 297, Contract AF-04 (695)-269 (Unclassified).

The three translational and three rotational equations of motion for a gravity-gradient stabilized satellite are derived. The effects of the Earth oblateness, magnetic field, solar radiation, aerodynamic drag, and any control forces are included. The usefulness of vector, matrix, and dyadic notation for derivation of equations is demonstrated and the results reduced to scalar form wherever possible.

854. Aerospace Corporation, Los Angeles, California,
GENERAL EQUATIONS OF MOTION FOR A GRAVITATIONALLY ORIENTED MULTIPLE-PART SATELLITE by V. Chobotov, September 1964, TDR-64 163, TDR-269 (4540-70)-8, AD-607 216, Contract AF-04(695)-269 (Unclassified).

The general equations of motion for a multiple-part satellite are presented. These equations are then specialized for a two-body satellite that has energy dissipation, which is subject to gravitational and other forces. By use of Euler angles and Euler parameters for various coordinate transformations, the scalar forms of the equations are derived. Methods for possible solution of the equations are discussed.

855. Aerospace Corporation, Los Angeles, California,
MOMENTUM BIAS ATTITUDE CONTROL FOR A SYNCHRONOUS COMMUNICATION SATELLITE by A. C. Barker, May 1964, TDR-269 4540, AD-601 807, Contract AF-04(695)-269 (Unclassified).

The purpose of the study was to establish the feasibility of mechanizing a proposed single-axis control system (momentum bias), and to obtain a set of approximate system design parameters. It is expected that the results will facilitate an evaluation of the single-axis system with respect to other attitude control schemes being considered. Analysis of vehicle dynamic behavior for the various environmental and self-induced disturbances encountered in space is an important part of the study. Results are expressed in both numerical and parametric form. A consequence of the study was the definition of a specific acquisition sequence. Criteria for parameter selection and a specific mechanization were developed. System dynamic response was studied in some detail.

856. Aerospace Corporation, Los Angeles, California,
SATELLITE VEHICLE ORBITAL TEST PLAN FOR ADVENT (U), July 1961, TDR-594 (1109) OTP-1, AD-358 065, Contract AF-04(647)-594 (Confidential).

This document presents the orbital test program to be executed for the evaluation of the ADVENT satellite vehicles. It defines objectives, tests required to satisfy the objectives, the orbital test organizational mode of operation, test operations, data evaluation and application procedures, and documentation for test planning, operations, and reporting test results.

Descriptions of the satellite and test facilities are referenced or included to facilitate understanding of the plan. Orbital tests begin at separation of the satellite from Stage II. Launch tests are all tests prior to that point.

857. Air Force Flight Dynamics Laboratory, Research and Technology Division, Wright-Patterson Air Force Base, Ohio,
ANALYSIS OF THE INFLUENCES OF DIFFERENT PARAMETERS ON A REACTION JET SINGLE-AXIS SATELLITE ATTITUDE CONTROL SYSTEM, TECHNICAL REPORT, MARCH - JUNE 1965 by H. P. Riemann, August 1965, FDL-TR-65-153, AD-473 341, Contract AF-8225 822509 (Unclassified).

This report presents the results of a study to accumulate quantitative tradeoff information which can be used directly as a design aid in space vehicle attitude control synthesis. The objective of the study was to give a survey on the influence of the various control parameters. This was accomplished through the plotting of the calculated data.

858. Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio,
AN ANALYSIS OF COMPENSATION TECHNIQUES AND SENSOR NONLINEARITIES IN A MASS EXPULSION SINGE-AXIS SATELLITE ATTITUDE CONTROL SYSTEM, MASTER'S THESIS by R. G. Cronquist and D. W. Welp, June 1964, GGC/EE/64 6, AD-603 954 (Unclassified).

The prime objective of the investigation was to analyze compensation techniques and sensor nonlinearities in a mass expulsion attitude control system. Three conventional compensators and combinations of these are analyzed and the results presented and compared for acquisition and limit cycle operation. Based primarily on the criterion of low fuel consumption, the rate gyro compensator is best for acquisition while the pseudo-rate compensator is best for limit cycle. The effects of sensor nonlinearities are analyzed for rate and displacement gyros. The rate gyro deadzone produces the only significant effect on the system. This deadzone considerably increases the fuel consumption in the limit cycle. As an extra objective, a unique compensation technique is derived which greatly decreases fuel consumption during acquisition.

859. Air Force Institute of Technology, Wright-Patterson Air force Base, Ohio,
DESIGN OF A CONSTANT ATTITUDE TARGET FOR RENDEZVOUS WITH REMOTE MANEUVERING UNIT, MASTER'S THESIS by A. J. Willoughby, August 1964, GSP/PHYS/64 14, AD-603 617 (Unclassified).

A target satellite is designed to provide a test of the remote maneuvering unit's rendezvous, television and radar capabilities, and meet certain requirements imposed by NASA. A Fortran program is developed to calculate target trajectories based on perturbation theory and an atmospheric model which considers oblateness, solar heating,and rotation.

860. Air Force Systems Command,
TRANSACTIONS OF THE SEVENTH SYMPOSIUM ON BALLISTIC MISSILE AND SPACE TECHNOLOGY VOLUME II - EARTH SATELLITE CONTROL AND CONTROL SYSTEMS CONTROL OF MANNED SPACE ENVIRONMENT SIMULATION COMMUNICATIONS, 16 August 1962, AFSC Sym-BM & ST-7, Vol. 2 (Unclassified).

The second volume of these transactions contains the unclassified papers presented at the symposium, and covers the following categories:

1) Earth satellite control and control systems.
2) Control of manned space environment.
3) Simulation.
4) Communication.

861. Air Force Systems Command, Foreign Technology Division, Wright-Patterson Air Force Base, Ohio,
A CLASS OF ATTITUDE-CONTROL SYSTEMS OF ARTIFICIAL EARTH SATELLITES by V. A. Bodner, K. B. Alekseev, and G. G. Bebenin, June 1965, FTD-MT-65-119, AD-622 605 (Unclassified).

This report is concerned with the synthesis of circuits of control systems with flywheels and of those with momentum magnetic drive.

862. Air Force Systems Command, Foreign Technology Division, Wright-Patterson Air Force Base, Ohio,
MAIN GOALS OF THE HISTORICAL FLIGHT by B. Semenov, March 1963, AD-401 727 (Unclassified).

This report discusses space capsule control systems used by cosmonauts during orbital flight.

863. American Institute of Aeronautics and Astronautics, New York, New York,
CONTROL OF THE ATTITUDE AND POSITION OF A SYNCHRONOUS SATELLITE BY CONTINUOUS RADIAL THRUST by R. S. H. Toms and B. E. Kalensher, 1963, AD-407 770 (Unclassified).

The motion of a satellite in an arbitrary circular orbit resulting from the action of small, continuous forces acting circumferentially, radially, and normally to the orbit is investigated. A correlation is made between this motion and that of an equatorial synchronous satellite undergoing corrective orbital maneuvers by a single thrustor, nominally pointing in a radial direction, but vectored to produce circumferential, normal, and incremental radial thrust components. A system is described employing this type of thrustor, and this system is shown to be competitive with a multiple-thrustor system for long-life satellites.

864. American Rocket Society,
A NEW METHOD OF ATTITUDE CONTROL UTILIZING THE EARTH'S MAGNETIC FIELD FOR LONG LIFE SPACE VEHICLES by A. G. Buckingham, 9 August 1961, ARS Reprint 1915-61 (Unclassified).

This paper was presented at the Guidance, Control, and Navigation Conference, 7-9 August 1961, at Stanford University. Attitude control systems may be classified into two general categories depending upon the type of actuation system employed. One type utilizes a mass-dispensing torque generation system such as compressed gas or chemical propellant and a second type manipulates the natural forces of the space environment such as aerodynamic pressure, solar pressure, Earth's mass attraction, and magnetically coupled forces. This paper presents the theory of operation, the mechanization, and the results of investigations made utilizing the electromagnetic coupling method to perform attitude control.

865. American Rocket Society,
DESIGN CONSIDERATIONS FOR SPACE VEHICLE REACTION CONTROL A-C SERVOMOTORS by T. Bernstein and D. R. Howard, 9 August 1961, ARS Reprint 1916-61 (Unclassified).

This paper was presented at the Guidance, Control, and Navigation Conference, 7-9 August 1961, at Stanford University. Inertial storage of momentum in a rotating mass offers a relatively simple method for controlling the attitude of a satellite through creation of reaction torque on the vehicle. A system of rotating masses may be designed to use sensor information in such a manner that approximate linear, damped control of the vehicle is possible within the capability of the reaction control device. Several configurations of reaction control devices have been proposed for study and development.

866. Army Ballistic Missile Agency, Redstone Arsenal, Alabama,
REQUIREMENTS FOR ATTITUDE CONTROL OF SATELLITES AND SPACE VEHICLES by J. S. Farrior (Unclassified).

The problem of attitude control exists to a certain extent with all kinds of vehicles, missiles, and projectiles. Attitude control is necessary or desirable to provide mental and physical comfort for passengers, proper environment and positioning to allow instrumentation to function, and proper alignment for lift surfaces and thrust vectors.

867. Author Unknown,
CHECKING OUT OAO CONTROL, ISA Journal, Vol. 12, June 1965, 26 pp.

Not abstracted.

868. Author Unknown,
CONTROL SYSTEM FOR AN ORBITING OBSERVATORY, Electro-Tech, Vol. 73, May 1964, pp. 12-13.

Not abstracted.

869. Author Unknown,
NEW CONTROL SYSTEM FOR WEATHER SATELLITE, Franklin Institute Journal, Vol. 271, February 1961, pp. 162-163.

Not abstracted.

870. Author Unknown,
PRE-FLIGHT FOR TIROS II, Machine Design, Vol. 32, 8 December 1960, 10 pp.

Not abstracted.

871. Author Unknown,
REACTION WHEELS FOR ADVENT AND NIMBUS ATTITUDE CONTROL, Space/Aeronautics, Vol. 38, November 1962, 159 pp.

Not abstracted.

872. Author Unknown,
SATELLITES; SYNCOM CONTROL SYSTEM, Product Engineering, Vol. 34, 11 November 1963, 83 pp.

Not abstracted.

873. Author Unknown,
SIMULATOR FINAL-TESTS SATELLITE CONTROL HARDWARE, Machine Design, Vol. 34, 22 November 1962, 26 pp.

Not abstracted.

874. Author Unknown,
600-FT ROD CONTROLS SATELLITE, Mechanical Engineering, Vol. 85, 7 March 1963, pp. 56-57.

Not abstracted.

875. Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland,
AN IMPROVED THEORY OF MOTION OF AN ARTIFICIAL SATELLITE by B. Garfinkel, February 1964, BRL Report No. 1242 (Unclassified).

The paper deals with the problem of motion in the potential field defined by

$$V = -\frac{1}{r} + \frac{J_2 P_2 (\sin \theta)}{r^3} + \frac{J_4 P_4 (\sin \theta)}{r^5} ,$$

where J_2 and J_4 are small parameters, with $J_4 = 0(J_2^2)$.

The disposable constants c_1, c_2, and c_3 of the author's intermediate orbit (1958) are revised so as to incorporate the known secular variations up to the second order, furnished by the perturbation theory (1959). The revised algorithm provides a more accurate final orbit, incorporating a substantial fraction of the Keplerian secular variations of third order. An internal check of the theory is carried out by a comparison of the natural frequencies of the orbit with those of a perturbed ellipse.

876. Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland,
ZONAL HARMONIC PERTURBATIONS OF AN ARTIFICIAL SATELLITE by B. Garfinkel, May 1964, BRL 1246 (Unclassified).

This report extends the known solution of the main problem of the Artificial Satellite Theory to include the effects of all the higher zonal harmonics of the geopotential. The method of von Zeipel is used to calculate the secular and the long-periodic variations of orders J_1 and J_m/J_2, respectively.

877. Bauerschmidt, D. K.,
CONTROLLING ATTITUDE OF MANNED SATELLITES, Electronics, Vol. 34, 27 January 1961, 62 pp.

Not abstracted.

878. Beachley, N. H., Martin, L. B., and Otten, D. D.,
TESTING OGO'S ATTITUDE CONTROLS, Control Engineering (USA), Vol. 11, No. 10, October 1964, pp. 93-98.

After all the digital and analog computer analyses and simulations are done, a satellite's actual attitude control system must be tested before the irrevocable launch can be undertaken. When individual attitude control axes are decoupled sufficiently to permit testing the control systems one at a time, the single-axis simulator technique used on OGO offers an excellent simulation of the low torque environment of space, at low cost compared to other approaches. A suspended table (on a long low-torsion wire servoed at the top to reduce torsion) requires 170 hours to accumulate a position error of only one milliradian.

879. Bell Aerospace Corporation, Buffalo, New York, STUDY OF REQUIREMENTS FOR THE SIMULATION OF RENDEZVOUS AND DOCKING OF SPACE VEHICLES, REPORT FOR APRIL 1962 - JULY 1963 by J. M. Ryken, J. E. Emerson, G. T. Onega, and J. L. Bilz, October 1963, TDR-63 100, AD-425 499, Contract AF-33(657)-8620 (Unclassified).

This report presents results of a study to establish computer requirements for the simulation of rendezvous and docking systems in space vehicles. A literature search was made to establish rendezvous and docking systems which have been proposed. A complete simulation of a representative automatically controlled rendezvous and docking system was formulated and programmed on an IBM-7090 digital computer. Sufficient flexibility was incorporated into this simulation so that the proposed rendezvous and docking techniques could be studied. This program was used to determine digital computer requirements for the simulation of rendezvous and docking systems. Mission runs were made covering terminal guidance, docking, departure, retro, and deorbit to the Earth's atmosphere. A simplified simulation of rendezvous and docking was programmed on analog computers and coupled with a cockpit simulator. This simulation included an electronic image generation of a target vehicle as viewed by an astronaut through a window in the interceptor vehicle.

880. Bender, E. K. SAMPLED-DATA VELOCITY VECTOR CONTROL OF SPACECRAFT, ASME Paper 63-WA-314 for Meeting 17-22 November 1963, 11 pp.

Two-dimensional steering of spacecraft, incorporating time shared digital computer, during orbital transfer maneuver is investigated. Effects of sampling and holding, and pulse width modulation on attitude correction maneuver performed in response to prealignment error are studied. Amount of additional fuel consumed for entire orbital transfer maneuver due to initial error is shown to be dependent on four factors.

881. Bendix Corporation, Southfield, Michigan,
APPLICATION OF HIGH MOMENT-PRODUCING TECHNIQUES FOR CONTROL OF A MANNED SPACE VEHICLE, FINAL REPORT, March 1964, TDR-64 32, AD-439 201, Contract AF-33 (657)-10998 (Unclassified).

High moment-producing techniques are applied to the attitude control of manned space vehicles which performed orbital transfer, rendezvous, and lifting reentry maneuvers. The specific accomplishments were:

1) Establishment of control system, subsystem, and component requirements for critical vehicle flight phases.
2) Analysis of promising techniques for performing the flight control functions required during the various maneuvers.

882. Bendix Corporation, Southfield, Michigan,
APPLICATION OF HIGH MOMENT-PRODUCING TECHNIQUES FOR CONTROL OF A MANNED SPACE VEHICLE, FINAL SUMMARY REPORT, March 1964, TDR-64 32, AD-439 202, Contract AF-33 (657)-10998 (Unclassified).

The application is studied of high moment-producing techniques for the attitude control of manned space vehicles which perform orbital transfer, rendezvous, and lifting reentry maneuvers. The specific accomplishments were:

1) Establishment of control system, subsystem, and component requirements for critical vehicle flight phases.
2) Analysis of promising techniques for performing the flight control functions required during the various maneuvers.

A hypothetical vehicle was selected and its space mission was analyzed to determine the attitude control requirements. The rendezvous and reentry maneuvers were found to be especially demanding on the attitude control system.

883. Bick, J. H.,
ELECTROMAGNETIC TORQUES OPERATING ON SATELLITES USING SNAP REACTOR POWER SYSTEMS, AIAA Journal, Vol. 1, April 1963, pp. 963-964.

Not abstracted.

884. Bigot, C.,
STABILIZATION AND ATTITUDE CONTROL OF SATELLITES (Stabilization Et Commande D'attitude De Satellites), Technique et Science Aéronautiques et Spatiales, July-August 1965, pp. 305-314 (Journées d'Etudes Spatiales, Toulouse, France, May 23-28, 1964, Paper.) (In French, A66-15192).

Review of techniques which are applicable to the control and stabilization of satellites, including active stabilization, passive stabilization, and a study of orbital perturbations. The satellite OSO-1 is approximately stabilized by gyroscopic action created when the satellite is caused to rotate by jets of gas; independent fine-attitude control is provided for certain of the instruments. The OGO satellite uses three inertial wheels for stabilization. Syncom II maintains a stationary position with respect to the Earth by means of an auxiliary thrust motor. The perturbing effect of gravity gradients and of the Earth's magnetic field on satellite orbits is analyzed; aerodynamic effects, solar pressure, and the effect of meteorites are considered. Gravity-gradient (passive) stabilization systems are discussed, and various types of active stabilization are described.

885. Blatz, W. J.
GEMINI DESIGN FEATURES, Astronautics and Aeronautics, Vol. 2, November 1964, pp. 30-40.

Not abstracted.

886. Boeing Co., Seattle, Washington,
EFFECT OF GRAVITY GRADIENT ON ATTITUDE CONTROL OF A SPACE STATION by D. J. Liska, October 1964, AD-451 794 (Unclassified).

A comprehensive analysis is made of the attitude control impulses required to counteract gravity gradient torque on a sun-oriented Earth-orbiting space vehicle. The analytical approach divides the gravity gradient torque into components

according to significant frequencies. The analysis uses a unique orbit referenced, quasi-inertial coordinate system into which the disturbance impulse vector is resolved. A long period impulse component at twice orbit precession frequency appears along a coordinate axis in the orbit plane and perpendicular to the sun line-of-sight. Shorter period components at twice orbital frequency appear along the other two coordinate axes. The short period components can be controlled entirely with momentum exchange devices but the long period component should be discharged with reaction jets. By fully utilizing the short term storage capability of momentum exchange devices and applying combinations of controlled motions of the vehicle about its sun oriented axis, the propellant consumed in overcoming the long period disturbance is shown to be significantly reduced. The advantage of intentionally misaligning the vehicle axis from the sun line-of-sight is also shown.

887. Boeing Co., Seattle, Washington,
EFFECT OF GRAVITY GRADIENT ON ATTITUDE CONTROL OF A SPACE STATION by D. J. Liska and W. H. Zimmerman, June 1964, AD-442 393, (Presented at Space Station Symposium, Pasadena, California, 15 April 1964) (Unclassified).

Derivations of the torque produced by the gravitational gradient on an orbiting body have appeared in the literature on several occasions. Two classes of problems have received considerable attention. The first involves the generalized motion of a body under the influence of the gravity torque alone when released from an arbitrary set of initial restraints, and the second deals with the application of the gravity torque as a medium of passive attitude or orientation control. For the purpose of analyzing the gravity torque on a solar-oriented vehicle, it is very important to make the right choice of coordinate system in which the vector representation is obtained. By proper choice of coordinates, the complex nature of the gravity torque can be reduced and described with clarity as three systematically behaving vector components. These components can be pictured physically with little difficulty and under certain conditions can be easily integrated to yield the disturbance impulse, an attitude control criterion. Therefore, the purpose of this paper is to present a derivation of the gravity torque in the most useful coordinates and to interpret the resulting torque impulse components in a manner applicable to sun-oriented vehicle attitude control.

888. Brady, M. E.,
SPACECRAFT TECHNOLOGY FOR SATELLITE COMMUNICATION SYSTEMS, Electrical Communication, Vol. 39, No. 1, 1964, pp. 144-154.

Not abstracted.

889. Buckingham, A. G.,
THE PRESENT STATUS OF ELECTROMAGNETIC TECHNIQUES FOR SPACE VEHICLE ATTITUDE SENSING AND ACTUATION, American Institute of Aeronautics and Astronautics, Guidance and Control Conference, Cambridge, Massachusetts, 12-14 August 1963, Paper 63-331, 10 pp. (A63-21594).

This article presents brief appraisal of the state-of-the-art of electromagnetic attitude control to recommend the applied research needed to improve the capabilities of electromagnetic actuation for future space vehicles. Reviewed are the results of an examination, using digital and analog computers, of the characteristics and capabilities of several of the second-generation active electromagnetic actuation techniques. The application, mechanization, and performance of the latter are discussed for wheels-and-coils systems and coils-and-gravity gradient systems. An evaluation is made of present knowledge of the Earth's magnetic field and the usefulness of electromagnetic devices as both sensors and actuators in Earth-orbiting missions.

890. Byrne, B., Murphy, W., and Lanzkron, R. W.,
GIMBALLESS INERTIAL REFERENCE SYSTEM, Institute of Radio Engineers, International Convention, New York, New York, 26-29 March 1962 (1962 IRE International Convention Record. Part 5 - Aerospace and Navigational Electronics; Military Electronics; Radio Frequency Interference; Space Electronics and Telemetry, Vol. 10, pp. 163-174) (A63-12528).

Discussion of the requirements for a vehicle which uses a gimballess electronic inertial package as its inertial reference. The system considered consists of three strap-down (body-mounted) rate gyros, three accelerometers, and a digital differential analyzer. The output of this package is equivalent to that of a conventional gimbaled inertial platform. The design considerations and requirements of the gyro loop, the analog-to-digital conversion system, and the digital differential analyzer are discussed at length. Worked out in detail is an

example in which the system components are combined into an inertial reference package suitable for a reentry mission.

891. Carroll, P. S.,
EQUATIONS OF MOTION FOR SPIN STABILIZATION ANALYSIS IN TERMS OF EULER ANGLES, AIAA Journal, Vol. 2, August 1964, pp. 1483-1485 (A64-22725).

This paper presents a suggestion for improving the procedure of space-vehicle spin stabilization analysis. It is stated that most of the literature on spin stabilization analysis of space vehicles approaches the problem by first solving the Euler equations of rotational motion in terms of body rates. This approach has been especially prevalent when the spinning body is influenced by external torques, which are usually expressed in body coordinates. In the present paper, linearized equations of satellite rotational motion are derived directly in terms of Euler angles. The equations include terms containing external torques so that substitution of proper expressions for these torques will allow direct solution for a variety of cases such as responses to impulsive control torques or natural disturbance torques.

892. Carroll, P. S.,
TORQUE ON A SATELLITE DUE TO GRAVITY GRADIENT AND CENTRIFUGAL FORCE, AIAA Journal, Vol. 2, December 1964, pp. 2220-2222.

Not abstracted.

893. Chute, F. S. and Walker, G. B.,
THE POSSIBILITY OF STABILIZING A SPACE VEHICLE USING ELECTROMAGNETIC ANGULAR MOMENTUM, Canadian Aeronautics and Space Journal, Vol. 11, September 1965, pp. 219-225 (Canadian Aeronautics and Space Institute, Astronautics Symposium, Toronto, Canada, 15 February 1965, Paper) (A65-33454).

This paper presents a proposed alternative to the usual methods of removing unwanted momentum (exhaustion of mass through a gas jet nozzle, use of the Earth's magnetic field, control of current in a set of mutually perpendicular coils aboard the vehicle, inertial wheels, use of gravitational gradients, plasma emissions, maneuverable sails and paddles, etc.) based on the production of electromagnetic angular

momentum aboard the spacecraft. Control torques are produced by radiating suitably polarized waves from an antenna mounted on the spacecraft. Two possible antenna configurations are discussed. Also considered is the retarding torque exerted on a spinning antenna. It is shown that, while this torque is present in almost every space application, it is practically negligible.

894. Cole, R. D.,
ATTITUDE CONTROL OF ROTATING SATELLITES, ARS Journal, Vol. 31, October 1961, pp. 1446-1447.

Not abstracted.

895. Cook, J. M.,
OAO INITIAL STABILIZATION AND CONTROL, Astronautics and Aerospace Engineering, Vol. 1, Setpember 1963, pp. 88-95.

Not abstracted.

896. Craig, B. D.,
NUTATION DAMPER FOR OSO, Astronautics and Aerospace Engineering, Vol. 1, December 1963, pp. 50-55.

Not abstracted.

897. Crocker, M. C., II and Vrablik, E. A.,
EXPERIMENT IN SOLAR ORIENTATION OF SPIN STABILIZED SATELLITE, AIAA Journal, Vol. 3, July 1965, pp. 1350-1351.

Not abstracted.

898. Crow, R. K. and Horwitz, H. P.,
NONLINEARSTUDY OF AN ATTITUDE CONTROL SYSTEM FOR ORBITAL SPACE VEHICLES, North Hollywood, California, Western Periodicals Co., 1963, pp. 2.2.2-1 to 2.2.2-20, Conference sponsored by the Baltimore Section of the Institute of Electrical and Electronics Engineers and the Professional Technical Group on Aerospace and Navigational Electronics (In: Annual East Coast Conference on Aerospace and Navigational Electronics, 10th, Baltimore, Maryland, 21-23 October 1963, Proceedings) (A64-18284).

This article presents an investigation of the precise three-axis attitude control of an orbital space vehicle. The equations

of motion are general and designed to encompass many of the parameters that will influence an orbital space flight and will not be constrained by specific vehicle geometry, construction, orientation, or trajectory. The primary source of actuation is a set of three orthogonal reaction wheels which provide control torques and integrate the disturbance torques along each axis. It is stated that, because of the gyroscopic effects of the rotating masses, an interdependency exists between the various axes. The extent of these effects is investigated.

899. Defense Documentation Center, Redstone Arsenal, Alabama, SATELLITE ATTITUDE CONTROL SYSTEMS, THRUST VECTOR CONTROL SYSTEMS, SECONDARY INJECTION, ADAPTIVE CONTROL SYSTEMS, July 1962, ASTIA/ARB 13001 (Unclassified).

This report consists of catalog cards on the following subjects:

1) Satellite attitude control systems.
2) Thrust vector control systems secondary injection.
3) Adaptive control systems.

900. Demetriades, S. T.
MAGNETOHYDRODYNAMIC ORBIT CONTROL FOR SATELLITES, Electrical Engineering (USA), Vol. 79, No. 12, December 1960, pp. 987-995.

Successful orbit control requires electric propulsion systems capable either of frequent refueling and/or of very high specific impulse. The theory of the magnetosdynamic (MGD) ram-jet and the MGD rocket is developed and the power requirements as well as some of the design considerations are given. Practical problems are outlined and some of the present equipment is described.

901. Dickstein, D. H.,
CAPTURE OF A PASSIVELY STABILIZED SATELLITE BY EARTH'S GRAVITY FIELD, AIAA Journal, Vol. 1, October 1963, pp. 2399-2401.

Not abstracted.

902. Dobronravov, V.,
FLIGHT CONTROL OF A SPACESHIP (Upravlenie Kosmicheskim Korablem), Kryl'ia Rodiny, Vol. 13, September 1962, pp. 12-13 (In Russian) (A63-15935).

Discussion of some of the problems related to the mechanics of flight control of space vehicles. Particular attention is given to the principles of operation and use of gyroscopes, inertial platforms, and control jets. Some of the techniques used in the control of early Soviet and U.S. spacechips are mentioned.

903. Donovan, R. F.,
DEVELOPMENT OF FLIGHT CONTROLLER FOR DELTA SPACE RESEARCH VEHICLE, AIEE Transactions, Vol. 79, Pt. 2 (Applications and Industry) No. 51, November 1960, pp. 406-411, Paper 60-1039.

Major problems encountered and solved in development of individual units, such as programmer, gyroscope assembly, electronics package and static inverter, and system testing.

904. Douglas Aircraft Co., Inc., Santa Monica, California,
ORBITAL SPACE STATION STUDY, VOLUME III, APPENDIX B, EXPERIMENT DEFINITIONS, PART 6, EXPERIMENTS 97 THROUGH 116-1 (U), September 1964, TR-212, Vol. 3, AD-353 816, Contract AF-04(695)-560 (Secret).

Not abstracted.

905. Drake, J. E. and Jackson, D. B.,
CONCEPTS AND TECHNIQUES FOR ATTITUDE CONTROL, DYNAMIC BALANCE AND STABILIZATION OF MANNED, ROTATING SPACE STATION, American Astronautical Society - Advances in Astronautical Sciences, Vol. 16, Pt. 1, 1963, pp. 384-401.

Several systems necessary for angular motion control of large, manned, rotating space station during routine orbital operation are considered; reaction jet attitude control systems are discussed with emphasis on simplicity of operation and optimization of fuel consumption; promising stabilization methods appear to be angular momentum wheels, pulse jet pairs, passive mechanical or fluid devices, and nonrigid properties of station itself.

906. Drake, J. E, and Jackson, D. B.,
CONCEPTS AND TECHNIQUES FOR ATTITUDE CONTROL, DYNAMIC BALANCE, AND STABILIZATION OF A MANNED, ROTATING SPACE STATION, North Hollywood, California, Western Periodicals Co., 1963, pp. 384-401 (USAF and American Astronautical Society, Space Rendezvous, Rescue, and Recovery, Symposium, Edwards Air Force Base, California, 10-12 September 1963) (In: Advances in the Astronautical Sciences, Vol. 16, Pt.1, Space Rendezvous, Rescue, and Recovery) (A63-24765).

Discussion of the several systems necessary for the angular motion control of a large, manned, rotating space station during routine orbital operation. The problem is considered in the following three phases:

1) Attitude control.
2) Stabilization.
3) Dynamic balance.

Reaction jet attitude control systems are discussed with an emphasis on simplicity of operation and optimization of fuel comsumption. The more promising stabilization methods appear to be angular momentum wheels, pulse jet pairs, passive mechanical or fluid devices, and the nonrigid properties of the station itself. Precise control of the space station is shown to require accurate dynamic balance about its designed spin axis. The practicability of a dynamic balance system which produces torques in opposition to the constant or slowly changing imbalance torques is discussed.

907. Dzilvelis, A. A.,
SATELLITE ATTITUDE CONTROL SYSTEMS, Astronautics and Aerospace Engineers, Vol. 1, March 1963, pp. 78-82.

Not abstracted.

908. Emmerich, C. L.,
APPLICATION OF FLOATED GYROS IN GUIDED MISSILES AND SPACE VEHICLES (Anwendung der Schwimmkreisel bei Lenkgeschossen und in der Raumfahrt), Braunschweig, Friedr. Vieweg and Sohn, 1962, pp. 319-322 (In German, with Summaries in English and French) (WGL Tagung, Freiburg im Breisgau, Germany, 10-13 October 1961, In Wissenschaftliche Gesellschaft für Luftfahrt E. V., Jahrbuch, 1961 (A63-21864).

Comparison of the conditions for the application of floated gyros, nonfloated gyros, manned telescopes, and electronic startrackers. It is shown that floated gyros exhibit the best performance in flight in the vicinity of Earth or other planets. A small all-attitude inertial platform is described, in which floated gyros are used as the primary guidance components. Recent advances in the art of precision angle pickoff design and in the miniaturization of electronic control amplifiers are discussed.

909. Ergin, E. I. and Wheeler, P. C.,
MAGNETIC ATTITUDE CONTROL OF A SPINNING SATELLITE, Journal of Spacecraft and Rockets, Vol. 2, November - December 1965, pp. 846-850 (American Institute of Aeronautics and Astronautics, Annual Meeting, 1st, Washington, D. C., 29 June - 2 July 1964, Paper 64-235.) (A66-12735).

Not abstracted.

910. Etkin, B.,
DYNAMICS OF GRAVITY-ORIENTED ORBITING SYSTEMS WITH APPLICATION TO PASSIVE STABILIZATION, AIAA Journal, Vol. 2, June 1964, pp. 1008-1014.

Not abstracted.

911. Fairchild Hiller Corporation, Republic Aviation Division, Farmingdale, New York,
RESEARCH ON SATELLITE ATTITUDE CONTROL USING PLASMA PINCH ENGINES, FINAL REPORT by E. Vogel, October 1965, AD-474 276L, Contract NONr-3957 (00) (Unclassified).

This is the final report covering theoretical considerations regarding the application of the plasma pinch engine to satellite attitude control. Both three-axis and two-axis controls are

considered, with emphasis on two-axis stabilization of a vehicle axis to the local vertical. Stability and cross coupling problems are investigated and methods of damping the free yaw axis are considered. Design rules for implementing such systems are given.

912. Fang, B. T.,
KINETIC ENERGY AND ANGULAR MOMENTUM ABOUT THE VARIABLE CENTER OF MASS OF A SATELLITE, AIAA Journal, Vol. 3, August 1965, pp. 1540-1542.

Not abstracted.

913. Fischell, R. E.,
SPIN CONTROL FOR EARTH SATELLITES, APL Technical Digest, Vol. 5, September - October 1965, pp. 8-13(A66-14521).

A magnetic torqueing system has been developed for controlling satellite spin rate and spin (Z) axis orientation. The spin rate control system consists of two vector magnetometers whose outputs are amplified and properly phased to provide a constant-amplitude magnetic dipole moment perpendicular to the projection of the Earth's magnetic field in the satellite X-Y plane. This torque can be used to increase or decrease the satellite spin rate. Spin axis orientation is obtained by commanding on a magnetic dipole moment in the Z-direction. When activated, this magnetic moment causes the satellite to precess to a desired orientation, at which time the dipole moment is restored to zero.

914. Garber, T. B.,
INFLUENCE OF CONSTANT DISTURBING TORQUES ON THE MOTION OF GRAVITY-GRADIENT STABILIZED SATELLITES, AIAA Journal, Vol. 1, April 1963, pp. 968-969.

Not abstracted.

915. General Electric Co., Johnson City, New York, RESEARCH AND INVESTIGATION ON SATELLITE ATTITUDE CONTROL, PART I. A SUMMARY, PART I. B DESIGN GUIDE, TECHNICAL REPORT, JANUARY 1963 - APRIL 1964 by K. C. Nichol, March 1965, AD-468 354, Contract AF-33 (657)-7717 (Unclassified).

The results are presented of a study to accumulate quantitative trade-off information which can be used directly as a design aid in space vehicle attitude control synthesis. The objective of the study was to prepare design data such that when the specific vehicle mission is defined, the optimum attitude control system (in terms of weight, performance, reliability, and related energy source) can be designed and constructed.

916. General Electric Co., Johnson City, New York, RESEARCH AND INVESTIGATION ON SATELLITE ATTITUDE CONTROL, PART II. INVESTIGATION OF SPACE VEHICLE ATTITUDE CONTROL TECHNIQUES, TECHNICAL REPORT, JANUARY 1963 - APRIL 1964 by K. C. Nichol, March 1965, TR-64-168-PT-2, AD-468 355, Contract AF-33(657)-7717 (Unclassified).

Information and performance data are presented which have been obtained on the various methods of space vehicle attitude control which have been investigated. The study of four primary control techniques is as follows:

1) Inertia wheel.
2) Fluid flywheel.
3) Gyroscopic.
4) Conventional mass expulsion control systems.

Three techniques include descriptions of the many different components which may comprise each system and the selection of the optimum components for various mission requirements. Steady state and dynamic analyses were performed on these systems to determine their ability to meet the requirements of present and future space vehicles. Control systems were then synthesized for the various control requirements.

917. General Electric Co., Johnson City, New York,
RESEARCH AND INVESTIGATION ON SATELLITE ATTITUDE CONTROL. PART IV. FLUID FLYWHEEL ATTITUDE CONTROL MODEL, TECHNICAL REPORT JANUARY 1963 - APRIL 1964 by K. C. Nichol, March 1965, TR-64-168-PT-4, AD-468 515, Contract AF-33(657)-7717 (Unclassified).

This report presents the results of a study to accumulate quantitative trade-off information which can be used directly as a design aid in space vehicle attitude control synthesis. The objective of the study was to prepare design data such that when the specific vehicle mission is defined, the optimum attitude control system (in terms of weight, performance, reliability, and related energy source) can be designed and constructed. To achieve the goal, the program was conducted in four main parts:

1) The investigation of attitude control systems (Part II).
2) Investigation of space power systems (Part III).
3) The preparation of a design guide (Part I).
4) Construction of an attitude control system model to validate the use of the design guide (Part IV).

918. General Electric Co., Light Military Electronics Department, Johnson City, New York,
ATTITUDE CONTROL AND STABILIZATION SYSTEM FOR AN ORBITING VEHICLE, FINAL REPORT, JULY 1962 - AUGUST 1964 by K. B. Haefner, May 1965, TR-64-165, AD-468 353, Contract AF-33(657)-9180 (Unclassified).

The purpose of the program was to develop an attitude control and stabilization system for a large (5500 pound) Earth-orbiting vehicle. The program consisted of an extensive system analysis, analog computer simulation, the fabrication of an experimental model control system, and the evaluation of control system performance on a full-scale, dynamic simulator. The control system developed under this program combined several new techniques explored individually under previous efforts. Namely, the use of momentumgyroscopes and hypergolic bipropellant reaction control jets as vehicle torquers, electronic control logic computation, and the improvement of reliability through selective redundancy. The experimental system, operated aboard a 30-foot long vehicle which was mounted on an air bearing in a special facility, met or exceeded the specified performance requirements.

919. General Electric Co., Missile and Space Division, Philadelphia, Pennsylvania,
COMMUNICATION SATELLITE PROJECT ADVENT BIBLIOGRAPHY, August 1961, AD-453 878, Contract AF-04(647)-476 (Unclassified).

CONTENTS

Contract Status Reports
Technical Operating Reports
Technical Reports
Notes
Specifications

920. General Electric Co., Missile and Space Division, Philadelphia, Pennsylvania,
COMMUNICATION SATELLITE PROJECT ADVENT, MONTHLY PROGRESS REPORT NO. 19, 16 MAY - 15 JUNE 1961 (U), June 1961, AD-362 807, Contract AF-04(647)-476 (Confidential).

Not abstracted.

921. General Electric Co., Missile and Space Division, Philadelphia, Pennsylvania,
COMMUNICATION SATELLITE PROJECT ADVENT, MONTHLY PROGRESS REPORT NO. 21, 16 JULY - 15 AUGUST 1961 (U), August 1961, AD-362 615, Contract AF-04(647)-476 (Confidential).

Not abstracted.

922. General Electric Co., Missile and Space Division, Philadelphia, Pennsylvania,
COMMUNICATION SATELLITE PROJECT ADVENT, MONTHLY PROGRESS REPORT NO. 26, 16 DECEMBER 1961 - 15 JANUARY 1962 (U), January 1962, AD-361 876, Contract AF-04(647)-476 (Confidential).

Not abstracted.

923. General Electric Co., Missile and Space Division, Philadelphia, Pennsylvania,
COMMUNICATION SATELLITE PROJECT ADVENT, PRELIMINARY DESIGN REPORT VOLUME 2 (U), 1961, AD-362 540, Contract AF-04(647)-476 (Secret).

Not abstracted.

924. General Electric Co., Missile and Space Division, Philadelphia, Pennsylvania,
COMMUNICATION SATELLITE PROJECT ADVENT, VOLUME I. SEMI-ANNUAL TECHNICAL REPORT FOR PERIOD ENDING 15 DECEMBER 1961 (U), January 1962, AD-362 628, Contract AF-04 (647)-476 (Confidential).

Not abstracted.

925. General Electric Co., Missile and Space Division, Philadelphia, Pennsylvania,
COMMUNICATION SATELLITE, PROJECT ADVENT, VOLUME II. SEMI-ANNUAL TECHNICAL REPORT (U), December 1961, AD-362 643, Contract AF-04(647)-476 (Confidential).

Not abstracted.

926. General Motors Corporation,
DEVELOPMENT OF A SOLID PROPELLANT ATTITUDE AND VELOCITY CONTROL SYSTEM FOR MISSILES AND SPACE VEHICLES (U) by A. J. Sobey and R. C. Fall, 25 May 1961, GMC-EDR-2090, Contract NAS5-483 (Confidential).

This paper describes the development of a simple and reliable high performance solid propellant attitude and velocity control system for missiles and space vehicles.

927. General Motors Corporation,
DEVELOPMENT OF THE ROCKET VELOCITY AND ATTITUDE CONTROL SYSTEM FINAL SUMMARY REPORT (U), 29 May 1961, GMC-EDR-2137, Contract NAS5-483 (Confidential).

Not abstracted.

928. Gordon, R. L.
INTERNAL ALTITUDE TECHNIQUE FOR HYPERSONIC GLIDE VEHICLE GUIDANCE, IRE East Coast Conference on Aerospace and Navigational Electronics, Technical Paper 4.1.3 for Meeting 23-25 October 1961, 8 pp.

Method for providing stable, inertially derived altitude indiction is described; this method utilizes compensation technique based on inertial acceleration and velocity measurements and using stored density altitude relationships; application to guidance of hypersonic glide vehicles and to use in conjunction with Schuler loops of such vehicles is described, and results of REAC study are presented.

929. Grantham, W. D.
EFFECTS OF MASS-LOADING VARIATIONS AND APPLIED MOMENTS ON MOTION AND CONTROL OF MANNED ROTATING SPACE VEHICLE, May 1961, Technical Note D-803, 40 pp.

This article presents an analytical study made on Earth satellite space station, rotating to provide artificial gravity; results indicate that shifting of masses within rotating craft could bring about large oscillations in attitude angles; constant rate inertia wheels and jet reaction moments can be used to minimize undesirable motions.

930. Grasshoff, L. H.,
METHOD FOR CONTROLLING THE ATTIDUDE OF A SPIN-STABILIZED SATELLITE, ARS Journal, Vol. 31, May 1961, pp. 646-649.

Not abstracted.

931. Hanaway, J. F., Carley, R. R., and Vernon, J. A.,
GEMINI FLIGHT CONTROL SYSTEM PERFORMANCE DURING THE SECOND UNMANNED FLIGHT, Society of Automotive Engineers, 1965, pp. 308-315 (Aerospace Vehicle Flight Control Conference, Los Angeles, California, 13-15 July 1965, Proceedings, Conference Sponsored by the Society of Automotive Engineers and the National Aeronautics and Space Administration) (A66-10684).

Brief description of the flight control system of GT-2 and of the special measures taken to permit operation in an unmanned configuration. The second Gemini flight provided

the first opportunity to evaluate the spacecraft flight system performance in its actual operational environment. The post-flight evaluation proved the adequacy of the system and removed one of the constraints on the subsequent manned flights. The results of that evaluation are presented and discussed. The maneuvers required of the system during the mission are described as are the data and analysis procedures utilized. Finally, system performance during each maneuver or stage of the flight is examined and compared with that predicted in preflight studies and simulations.

932. Hering, K. W. and Hufnagel, R. E.,
INERTIAL SPHERE SYSTEM FOR COMPLETE ATTITUDE CONTROL OF EARTH SATELLITES, ARS Journal, Vol. 31, August 1961, pp. 1074-1079.

Not abstracted.

933. Holahan, J.,
ADVANCED SYNCOM; TECHNOLOGY FOR STATIONARY COMMUNICATIONS SATELLITES, Space/Aeronautics, Vol. 40, September 1963, pp. 79-86.

Not abstracted.

934. Honeywell Inc., Minneapolis, Minnesota,
CONTROL SYSTEM REDUNDANCY MECHANIZATION STUDY by E. Tesch, R. Plaisted, and J. Pukite, February 1963, TDR-62 772, AD-402 497, Contract AF-33(616)-7881 (Unclassified).

Not abstracted.

935. Honeywell Inc., Minneapolis, Minnesota,
STABILITY AND CONTROL STUDY FOR A MANNED ORBITAL RESEARCH LABORATORY PROGRESS REPORT, April 1963, Report No. 2A S44 2, AD-418 709 (Unclassified).

Not abstracted.

936. Hsu, J. C., Lim, Y. S., and Meyer, A. U.,
ON ACTIVE ATTITUDE CONTROL OF SATELLITES, IEEE Transactions Military Electronics (USA), Vol. MIL-9, No. 2, April 1965, pp. 107-115.

Three phases of active attitude control of an orbiting satellite are examined; the despinning mode, the reorientation mode, and the control mode. Each of these modes is considered in the light of requirements for long-life mission where the ratio of control torque to satellite inertia must be minimized. Investigations of the minimum amount of information necessary for a gravitationally stabilized satellite are also included. It is shown that yaw information may be dispensed within many cases. A discussion is included of a novel method of providing controlled damping of a gravitationally stabilized satellite by means of internal moving parts and frictional dissipation involving feedback. Some numerical results are given.

937. Hughes Aircraft Corporation, Culver City, California,
MANUAL ATTITUDE CONTROL SYSTEMS. VOLUME IV: SYSTEM INTERACTION EFFECTS by R. O. Besco, D. K. Bauerschmidt, R. W. Allen, G. G. Depolo, and C.J. Goddard, September 1964, NASA CR-68087, CSCL 22C, X66-10807, Contract NASw-620 (Unclassified).

This report contains the results of studies to determine the interaction effects between modes of control, display formats, and vehicle acceleration response characteristics of manual attitude control systems. System performance curves are presented illustrating optimum regions for system design characteristics and handling qualities parameters. A number of design parameters are presented permitting comparisons to be made between various system configurations.

938. Hultquist, P. F.,
GRAVITATIONAL TORQUE IMPULSE ON A STABILIZED SATELLITE, ARS Journal, Vol. 31, November 1961, pp. 1506-1509.

Not abstracted.

939. Hutchinson, I. N., Morrison, R. F., and Keller, J. L., STABILIZATION AND CONTROL OF CABLE-CONNECTED SPINNING SPACE STATION, Joint Automatic Control Conference, 22-25 June 1965, pp. 520-530.

Attitude control problems peculiar to flexibly connected spinning vehicle configuration which can provide artificial gravity environment to crew of manned space station; control concepts are established and control system equipment parameters are presented.

940. Institute for Defense Analyses, Arlington, Virginia, ATTITUDE CONTROL, STABILIZATION, AND ORBIT CONTROL SUBSYSTEMS OF EARTH SATELLITES (U) by J. Kaiser and J. S. Attinello, July 1962, TR-62 10, AD-345 885 (Secret).

Not abstracted.

941. Institute of the Aeronautical Sciences, AN ADAPTIVE SYSTEM FOR CONTROL OF THE DYNAMIC PERFORMANCE OF AIRCRAFT AND SPACECRAFT by H. P. Whitaker, 19 July 1959, IAS 59-100 (Unclassified).

This report discusses techniques for using a model as the dynamic response reference for a multiloop flight control system so as to make the system self-adaptive to changes in its operating conditions. In the application tested, the adaptive equipment was capable of stabilizing an unstable system using only one sample of response error, although additional samples were required to find the optimum parameter values.

942. International Business Machines, Incorporated, MARP REPORT ON BALLISTIC MISSILE FLIGHT CONTROL THEORY by G. W. Johnson, 26 January 1961, IBM 60-504-48 (Unclassified).

This document contains five sections of a general report on missile flight control theory. Its objectives are to provide sound technical basis to direct future research in the area of missile flight control and to provide a single unified document for control engineers in the field of ICBM missile flight control.

943. Jazwinski, A. H.,
QUADRATIC AND HIGHER-ORDER FEEDBACK GAINS FOR CONTROL OF NONLINEAR SYSTEMS, AIAA Journal, Vol. 3, May 1965, pp. 925-935.

Not abstracted.

944. Johns Hopkins University, Applied Physics Laboratory, Silver Spring, Maryland,
GRAVITY-GRADIENT ATTITUDE STABILIZATION FOR COMMUNICATION SATELLITES by F. F. Mobley, September 1964, TG-597, AD-608 968 (Unclassified).

Gravity-gradient attitude stabilization has been used successfully in a number of near-Earth satellites in recent months. After the pioneering effort of the Applied Physics Laboratory in the first successful demonstration of gravity stabilization in June 1963, this technique has become one of the basic elements of satellite technology. By January of 1964, three APL satellites had been vertically stabilized by the passive gravity-gradient technique and are expected to continue in this state indefinitely. A satellite of the Naval Research Laboratory was also stabilized successfully in January 1964. These developments are reviewed herein, and the problems of extending these techniques to higher altitude for use as communication satellites are discussed.

945. Johns Hopkins University, Applied Physics Laboratory, Silver Spring, Maryland,
ON THE DYNAMICS OF A SATELLITE STABILIZED BY WIRES, TECHNICAL MEMORANDUM by R. R. Newton, February 1966, TG-811, AD-479 217 (Unclassified).

The attiuude of a satellite can be made stable in all three vibration angles by a suitable arrangement of wires rather than rigid members to give the necessary vertical extent. In one stabilization method, four wires are connected to the main satellite body at points as far apart as possible. The other ends of the wires are connected to a small mass, yielding a pyramidal configuration. This paper analyzes the normal modes of libration and the response to perturbing torques of such a satellite. It is shown that the long axis of the main body should point in the direction of motion; that is, the main body should be held in a position of unstable equilibrium. It is also shown that the effects of radiation pressure and thermal

distortion are an order of magnitude smaller than for equivalent satellites using rigid structures.

946. Johns Hopkins University, Applied Physics Laboratory, Silver Spring, Maryland,
SATELLITE 1963 22A ATTITUDE STABILIZATION AND DAMPING, VOLUME II, July 1963, TG-508, AD-429 538 (Unclassified).

Satellite 1963 22A was designed to operate in a gravity-gradient stabilized position. APL's approach to the problem of making sure that the satellite would be captured with the desired end facing the Earth was to design the satellite with these special features, each of which has been used with a considerable measure of success in other APL-designed satellites:

1) An extensible boom with an end mass to achieve the dumbbell configuration when desired.
2) A mechanical yo-yo despin device to slow down the spin rate of the satellite imparted during launch.
3) Magnetic hysteresis rods to remove residual spin of the satellite to damp satellite oscillations during magnetic attitude control, and to damp the gravity gradient librations.
4) Solar and magnetic attitude sensors to determine the attitude of the satellite with respect to the sun and the Earth's magnetic field throughout its orbit.
5) An electromagnet to stabilize the satellite magnetically along the local magnetic field direction and with the desired end facing the Earth when desired and prior to extension of the boom.

After the boom is extended, the electromagnet is de-energized.

947. Kane, T. R. and Wang, C. F.,
STABILITY OF GYROSCOPES ORBITING IN A GRAVITATIONAL FIELD, AIAA Journal, Vol. 3, July 1965, pp. 1290-1293.

Not abstracted.

948. Katucki, R. J.,
GRAVITY-GRADIENT STABILIZATION, Space/Aeronautics, Vol. 42, October 1964, pp. 42-47.

Not abstracted.

949. Kershner, R. B.,
GRAVITY-GRADIENT STABILIZATION OF SATELLITES, Astronautics and Aerospace Engineers, Vol. 1, September 1963, pp. 18-22.

Not abstracted.

950. Kovit, B.,
REMOTE SPIN AND ATTITUDE CONTROL FOR SYNCOM, Space/Aeronautics, Vol. 37, February 1962, pp. 77-79.

Not abstracted.

951. Kurzhals, P. R. and Adams, J. J.,
DYNAMICS AND STABILIZATION OF ROTATING SPACE STATION, Astronautics, Vol. 7, No. 9, September 1962, pp. 25-29.

This article presents problems associated with dynamics of spinning bodies and study undertaken by NASA Langley Research Center by programming rigid-body equations of motion for station on IBM 7090; docking impacts, attitude-system torques, and transient crew movements were simulated and corresponding response of station evaluated; types of results obtained; work done on stability and attitude-control systems required and concept of wobble damper and backup pulse-jet damping and orientation system; results obtained indicate no major difficulties.

952. Lee, E. B.,
DISCUSSION OF SATELLITE ATTITUDE CONTROL, ARS Journal, Vol. 32, June 1962, pp. 981-982.

Not abstracted.

953. Leondes, C. T.,
ANALYSIS AND SYNTHESIS OF A PARTICULAR CLASS OF SATELLITE ATTITUDE-CONTROL SYSTEMS, Journal of the Aerospace Sciences, Vol. 29, December 1962, pp. 1433-1453.

Not abstracted.

954. Lewis, J. A. and Zajac, E. E.,
A TWO-GYRO, GRAVITY-GRADIENT SATELLITE ATTITUDE CONTROL SYSTEM, Bell System Technical Journal (USA), Vol. 43, No. 6, November 1964, pp. 2705-2765.

This article gives the results of an analytical and numerical study of a two-gyro, gravity-oriented communications satellite. The principal purpose of the study was to uncover and solve the analytical problems arising in the design of passive gravity-gradient attitude control systems. Although the study was directed at satellite orientation, it is felt that many of the techniques developed have general use in the investigation of dynamical systems. Both small and large motions about the desired Earth-pointing orientation are considered. In the small-motion study, the goal is simultaneous optimization of the transient response and the forced response to perturbations caused by orbital eccentricity, magnetic torques, solar torques, thermal rod bending, and micrometeorite impact. In the large-motion study, all possible equilibrium positions of the satellite are enumerated and then initial despin after injection into orbit, inversion of the satellite from one stable equilibrium position to another by switching of gyro bias torques, and the decay of transient motions resulting from large initial angular rates are considered. As a specific numerical example, a 300-lb satellite in a 6000-nm orbit, stabilized by a 60-ft extensible rod with a 20-lb tip mass, and by two single-degree-of-freedom gyros, each with an angular momentum of 10^6 cgs units is treated. Without a detailed discussion of hardware, it is concluded that such a system having a total weight of 50 to 75 lb including power supply will provide a settling time for small disturbances of less than one orbit and will hold the aerial pointing error within a few degrees.

955. Lockheed Missiles and Space Co., Sunnyvale, California, INCLINATION AND ECCENTRICITY CHANGES EFFECTED BY LOW-THRUST PROPULSION SYSTEMS by C. J. Golden, 1963, AD-406 676, Contract AF-33(657)-8232 (Unclassified).

Change in orbit inclination and eccentricity are often involved in missions performed in a strong central force field by low-thrust, power-limited propulsion systems. These changes are analyzed for constant thrust acceleration using standard expressions from celestial mechanics; inclination change is discussed first.

956. Lockheed Missiles and Space Co., Sunnyvale, California, PROGRAM ROE (REFLECTOR ORBITAL EXPERIMENT). PART IV. ATTITUDE CONTROL AND STABILIZATION FEASIBILITY STUDIES, REPORT FOR 20 JANUARY - 20 APRIL 1964 by A. J. Daughton, December 1964, AD-458 241, Contract AF-33(657)-10668 (Unclassified).

An essential element of the Spaceborne Solar Dynamic Power System is the rigorous employment of a precise attitude control system to provide continuous solar orientation for the 45- to 60-foot reflector. The spacecraft mission and thermal design considerations govern whether the reflector is rigidly fixed to a solar-oriented spacecraft (Configuration I) or mechanically coupled with a mission-oriented vehicle (Configuration II). Most of the study effort was devoted to Configuration II because complex problems are introduced by the static and dynamic coupling of the vehicle through the hinge. No significant design problems were encountered with the rigidly coupled Configuration I. For Configuration I, the choice between a mass expulsion attitude control system and a control system employing momentum exchange with mass expulsion backup depends on differences in the principal axes inertias and the magnitude of the thrustor lever arms.

957. Lockheed Missiles and Space Co., Sunnyvale, California, SLV-3/01 WORKING GROUP, NASA/S-01 RANGER PROGRAM LAUNCH REPORT FOR SLV-3, 215D; S-01, 10205-6005; RANGER RA-5 (U), November 1962, AD-364 259, Contract AF-04(695)-198, Contract AF-04(647)-592 (Confidential).

The Ranger 5 flight vehicle (SLV-3, 215D; S-01, 6005; Spacecraft RA-5) was launched on 18 October 1962 at 1159:07 EST from Complex 12, AMR. The purpose of the flight was to

inject the spacecraft into a lunar-coincident trajectory. Performance of all three vehicles was within the required parameters during the ascent phase of the flight. The spacecraft was injected into a trajectory that would require one-third of its course-correction capability to attain the designated impact area. A malfunction in the spacecraft, approximately 35 minutes after injection, rendered the spacecraft incapable of performing the midcourse trajectory correction, therefore, lunar impact was not achieved.

958. Loebel, M.,
SEVERAL LINEAR STABILIZATION AND REORIENTATION CONTROL SYSTEM CONFIGURATIONS FOR ROTATING, MANNED ORBITAL SPACE STATION, Progress in Astronautics & Aeronautics, Vol. 13, 1964, pp. 313-337.

Systems analyzed included a gyro torquer and rate gyro instrumentation for wobble damping, a gyro torquer and linear accelerometer instrumentation for wobble damping, a wobble damper of one or two plus reaction jets and sun sensor for reorientation, all reaction jet torquer with sun sensor/rate gyro instrumentation for orientation, all reaction jet torquer with sun sensor/accelerometer instrumentation for reorientation and two instrumentation schemes were presented.

959. Liska, D. J. and Zimmerman, W. H.,
EFFECT OF GRAVITY GRADIENT ON ATTITUDE CONTROL OF SPACE STATION, Journal of Spacecraft and Rockets, Vol. 2, No. 3, May - June 1965, pp. 419-425.

Analysis is made of attitude control impulses required to totally counteract gravity-gradient torque on sun-oriented, Earth-orbiting space vehicle; torque can be expressed in terms of three well-behaved vector components, which include short-period and cumulative torques; two gravity-gradient control laws, constant-angle and constant-rate, are developed; sun-error law is described which can be applied in conjunction with constant-angle and constant-rate control to futher reduce level of disturbance; details of optimum attitude-control system.

960. Lynn, G. E., Hurt, J. G., and Harriger, K. A., MAGNETIC CONTROL OF SATELLITE ATTITUDE, IEEE Transactions Communication Electronics (USA), No. 74, September 1964, pp. 570-575.

A method of obtaining a minimum-mass actuator system is derived from fundamental considerations, and somewhat idealized equations are formulated. The corrections required as a result of second-order qualifying conditions are considered and discussed. Criteria are presented for the selection of core materials as a function of the specifications for a particular application. A good compromise device can be fabricated using the composite structure technique. Experimental data, verifying the accuracy of the torque and actuator mass equations to within five per cent, are presented.

961. Lytle, A. D., DETERMINATION OF ORBITAL PARAMETERS BY USE OF ASTROGYRODYNAMICS CONCEPT, Journal of Spacecraft and Rockets, Vol. 2, No. 1, January - February 1965, pp. 44-49.

Concept couples dynamics of gyroscope with orbit equations. By varying gyro spin rate and precession torque to satisfy coupled equations resulting spin rate will also be cosine function about mean value. Amplitude of gyro spin rate variation is proportional to orbit eccentricity, period of spin rate variation being proportional to orbital period. Error signal may be formulated and astrogyro spin rate and precession torque incorporated as servoloop. Error derivatives and curves for given orbit are presented and least-squares technique is developed to minimize random and systematic errors.

962. Maclaren, A. P., A GAS-JET ATTITUDE-CONTROL SYSTEM FOR SATELLITES, Control (GB), Vol. 8, September 1964, pp. 446-450.

To observe the ultraviolet spectrum of selected stars, it is proposed to rotate a satellite-borne telescope with reference to a stabilized platform and set it to an accuracy of about ±2 foot. Star-lock telescopes give angular error information. The telescope is locked to the platform during observation on the dark half-orbit and reaimed at the next star on the program during the daylit half-orbit. The method of applying

control torques chosen was an on/off jet of propane vapo and the reasons for this choice are considered in detail. Two systems, both of the on/off type with a dead zone, were considered, one with simple phase advance and one with a negative feedback circuit round the jet valve switching amplifier. The performance of both systems has been studied on an analog computer.

963. Massachusetts Institute of Technology, Cambridge, Massachusetts,
DYNAMICS OF A SOLAR PRESSURE STABILIZED SATELLITE, MASTER'S THESIS by J. R. Carroll and R. C. Limburg, June 1965, NASr-249, AD-617 517 (Unclassified).

It is the objective of this thesis to investigate the body dynamics of a solar pressure stabilized satellite in a heliocentric orbit of nonzero eccentricity. The equations of motion for an unsymmetrical satellite are simplified by finding satellite equilibrium position and making small angle assumptions about this position to linearize the equations. The motions predicted by the simplified model are compared with digital computer solutions of the general equations of motion. Passive damping and injection of the satellite into orbit are investigated briefly. In its equilibrium position, the satellite has one principal axis along the radial line. Of the two remaining principal axes, the one with the greater moment of inertia is perpendicular to the orbital plane. For the simplified model, motion about the three principal axes can be uncoupled for small disturbances from equilibrium. Motion about the radial line is characterized by oscillations at approximately orbital frequency rate.

964. Massachusetts Institute of Technology, Lincoln Laboratory, Lexington, Massachusetts,
DESIGN OF ELECTROMAGNETIC TORQUE RODS, TECHNICAL NOTE by W. L. Black, December 1965, TN-1965-45, TDR-65-589, AD-627 600, Contract AF-49(628)-5167 (Unclassified).

This report is a compilation of considerations involved in the design of electromagnetic rods for satellite erection. Formulas are derived showing the effect of various choices of core and wire material and weight, number of cores, length of cores, number of turns per core, and wire area on the magnetic moment, hysteresis power, hold power, hold voltage,

and switching time. These formulas are then applied to the problem of producing a required magnetic moment at the least cost in weight and power consumption.

965. Massachusetts Institute of Technology, Lincoln Laboratory, Lexington, Massachusetts,
LES-4 SPIN AXIS ORIENTATION SYSTEM by E. A. Vrablik, W. L. Black, and J. L. Travis, 1 October 1965 (ESD-TDR-65-460, TN-1965-48, AD-624 358, N66-17000, Contract AF-19 (628)-5167.

This report deals with the design of a satellite stabilization system to maintain the angular momentum of a spin-stabilized satellite normal to the satellite's orbital plane. This orientation of the angular momentum allows a higher gain (narrower beam) antenna in the X-band communications link in the satellite. The stabilization system uses the Earth's magnetic field as a source of torque and requires no commands from the ground as all the error sensing components are satellite borne.

966. Michelson, I.,
DIRECT NONLINEAR STABILITY ANALYSIS OF KEPLERIAN ORBITAL MOTION, AIAA Journal, Vol. 1, July 1963, pp. 1661-1662.

Not abstracted.

967. Michelson, I.,
EQUILIBRIUM ORIENTATIONS OF GRAVITY-GRADIENT SATELLITES, AIAA Journal, Vol. 1, February 1963, p. 493.

Not abstracted.

968. Micro State Electronics Corporation, Murray Hill, New Jersey,
A STUDY OF THE STABILIZATION OF AN EARTH SATELLITE by F. A. Jazede, October 1962, AD-408 621, (Unclassified).

This study is concerned with the stabilization in attitude of an Earth satellite. In particular, two ways of obtaining good stabilization are studied, one by use of a gas rocket which yields a nonlinear system (on/off type) studied by the phase plane method and the other by use of flywheels; the stabilization is then a linear one. In both cases, it is shown that a great simplification can be introduced in the stability

equations by the introduction of some approximations. Even, in the nonlinear case, the approximations (practically always justified) bring an enormous simplification in the computations by suppressing the coupling between the three axes around which the stabilization is applied.

969. Minneapolis - Honeywell Regulator Co., DYNA-SOAR (STEP I) PRIMARY GUIDANCE SUBSYSTEM, SECONDARY ATTITUDE REFERENCE. THREE AXIS ERROR DETAILED SYSTEMS ANALYSIS (U), AD-347 737, Contract AF-33 (657)-7133 (Confidential).

Not abstracted.

970. National Aeronautics and Space Administration, APPLICATION OF DESCRIBING-FUNCTION ANALYSIS TO THE STUDY OF AN ON-OFF REACTION-CONTROL SYSTEM by E. C. Lineberry, Jr. and E. C. Foudriat, January 1961, NASA TN D-654 (Unclassified).

The describing-function technique has been used in the analysis of an automatic reaction-control system for the upper stages of a missile during its burning and coasting phase. Limit-cycle characteristics, corresponding duty cycles, and system-parameter effects on these quantities were determined. The results obtained by this analysis show good agreement with results obtained in an analog simulation including reaction-control hardware.

971. National Aeronautics and Space Administration, STUDY OF SYSTEMS USING INERTIA WHEELS FOR PRECISE ATTITUDE CONTROL OF A SATELLITE by J. S. White and Q. M. Hansen, April 1961, NASA TN D-691 (Unclassified).

Various possible inertia wheel systems are examined for suitability for precise satellite attitude control, and three of these systems, which appear more promising than the others, are analyzed in detail, using the Orbiting Astronomical Observatory as an example. Theoretical and experimental investigations show that the system which uses an error-rate network to provide damping is superior to the other two systems. Experimental data taken under laboratory conditions with relatively large extraneous disturbances show that a dynamic tracking error of less than ±0.5 second of arc was obtained.

972. National Aeronautics and Space Administration, THE ORBITING GEOPHYSICAL OBSERVATORY, A NEW TOOL FOR SPACE RESEARCH by G. H. Ludwig, August 1962, NASA TN D-1450 (Unclassified).

Now that larger launching vehicles are available, observatory-type spacecraft are being developed which make the integration of large numbers of complex experiments more practical. These spacecraft consist of basic structures, electrical power, thermal control, attitude control, and data handling systems. The Orbiting Geophysical Observatory (OGO) will carry 150 pounds of experiments to conduct investigations within and immediately outside the Earth's magnetosphere and exosphere. The capabilities of OGO are discussed, and the experiments which are being developed for the first OGO launching are listed.

973. National Aeronautics and Space Administration, Langley Research Center, Langley Station, Virginia, PERFORMANCE CHARACTERISTICS OF CONTROL MOMENT GYRO SYSTEMS FOR MANNED ORBITAL LABORATORIES by R. W. Will, 1964, NASA TM-X-56221, N66-18364 (Unclassified).

Vehicle characteristics for a typical manned orbital laboratory were reviewed, and the mission was outlined in order to define the stabilization and control requirements. Analytical methods by which pointing accuracy is obtained with momentum storage systems were established, and the actual mechanization of the system and its effect on laboratory performance were considered. System mechanization constraints, such as torque limits and gimbal stops, and laboratory disturbances were simulated in the laboratory equations of motion to isolate their primary effects on momentum storage system performance. The detailed analysis confirmed the value of such systems and identified many system mechanization characteristics such as selective desaturation logic, on-off actuation, and gimbal rate command which enhance the laboratory's performance; however, an experimental verification of system characteristics is required before a control concept capable of accurately performing the complex manned orbital laboratory mission can be defined.

974. National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama,
THEORY OF ARTIFICIAL STABILIZATION OF MISSILES AND SPACE VEHICLES WITH EXPOSITION OF FOUR CONTROL PRINCIPLES by R. F. Hoelker, June 1961, NASA TN D-555 (Unclassified).

The theory of artificial stabilization of missiles and space vehicles in propelled flight is serviced by a more rigorous method than has been done in the past. The relationship between the rotary loop and path loop in their reactions to artificialstabilization schemes is emphasized. The path reaction modes are classified by setting them into relation to two singular solutions, the drift minimum and lead minimum modes. Two interesting other control modes are developed, concerned with local lateral acceleration along the missile axis. These are the maximum comfort control mode and the method of controlling the center or hinge point of the motion resulting from the combination of the rotary with the path motion.

975. Naval Research Laboratory, Washington, D. C.,
DIRECTIONAL EQUILIBRIUM OF AN ARTIFICIAL SATELLITE ENVELOPING A NONUNIFORM REGION OF A GRAVITATIONAL FIELD, INTERIM REPORT by P. A. Crafton, October 1965, NRL-6321, AD-624 592 (Unclassified).

Certain artificial satellites used for communications and/or navigation require means of directional stabilization. If the satellite encompasses an essentially uniform region of the gravitational field, it is in neutral directional equilibrium in that force field. The creation of an artificial satellite with a discrete distribution of mass permits us to have a satellite encompassing a nonuniform region of the gravitational field although having a relatively low total mass. The basic mathematical relationships are developed that must be satisfied by any gravity-gradient satellite so that it has stable directional equilibrium . The satellite is assumed to have a discrete distribution of mass, and is assumed to be not subjected to other body forces, radiation forces, and disturbing forces.

976. Neufeld, M. J.,
ORBIT CORRECTION, Space/Aeronautics, Vol. 43, February 1965, pp. 48-55.

Not abstracted.

977. Newton, R. R.,
DAMPING OF A GRAVITATIONALLY STABILIZED SATELLITE, AIAA Journal, Vol. 2, January 1964, pp. 20-25.

Not abstracted.

978. Newton, R. R.,
STABILIZING A SPHERICAL SATELLITE BY RADIATION PRESSURE, ARS Journal, Vol. 30, December 1960, pp. 1175-1177.

Not abstracted.

979. Norsell, P. E.,
SYNCOM; SYNCHRONOUS COMMUNICATIONS SATELLITES, Astronautics and Aerospace Engineers, Vol. 1, September 1963, pp. 76-78.

Not abstracted.

980. Olds, R. H.,
ATTITUDE CONTROL AND STATION KEEPING OF A COMMUNICATION SATELLITE IN A 24-HOUR ORBIT, AIAA Journal, Vol. 1, April 1963, pp. 852-858.

Not abstracted.

981. Otten, D. D.,
ATTITUDE CONTROL FOR AN ORBITING OBSERVATORY; OGO, Control Engineers, Vol. 10, December 1963, pp. 81-85.

Not abstracted.

982. Paiken, M. and Fleizig, R.,
MOMENTUM CONTROL OF THE OAO SPACECRAFT UTILIZING THE EARTH'S MAGNETIC FIELD, International Astronautical Federation, International Astronautical Congress, 14th, Paris, France, 25 September - 1 October 1963, Paper 32, Contract No. NAS5-814 (A63-25666).

This article presents a description of the preliminary design of an advanced control technique which is incorporated in the Orbiting Astronomical Observatory (OAO). In this technique, the momenta of inertia wheels, which provide the basic control torques, are regulated by torques created by the interaction of current-carrying coils with the Earth's magnetic field. Functional block diagrams and mathematical models for the basic control and momentum regulation loops are described. The estimated OAO disturbance torque profile and Earth's magnetic field characteristics at orbit altitude are provided as input data for the subsequent analysis. The analytic methods are outlined for the determination of OAO attitude stability and pointing accuracy as well as for the effectiveness of the momentum regulation technique.

983. Paul, B.,
PASSIVE GRAVITATIONAL ATTITUDE CONTROL SYSTEM FOR SATELLITES, Bell System Technical Journal, Vol. 42, September 1963, pp. 2195-2238.

Not abstracted.

984. Payne, S.,
COMMUNICATION SATELLITES; NEW PROBLEMS IN CONTROL, Control Engineers, Vol. 8, February 1961, 35 pp.

Not abstracted.

985. Polstorff, W. K.,
DYNAMICS OF ROTATING SPACE STATION, Simulation, Vol. 3, No. 4, October 1964, pp. 24-39.

Reaction of space station to rotating machinery and to mass motion inside station is formulated taking into account angular impulse introduced by moving mass. Ways are discussed to minimize roll of vehicle, either by corrective motion of astronauts or by special control systems; computer programs developed for analysis of dynamics by simulation.

986. Pringle, R., TUMBLING MOTIONS OF AN ARTIFICIAL SATELLITE, <u>AIAA Journal</u>, Vol. 3, June 1965, pp. 1087-1095.

Not abstracted.

987. Purdue University, Lafayette, Indiana, SATELLITE ATTITUDE STABILIZATION BY MEANS OF SOLAR SAIL by R. J. Hegstrom, AD-442 382 (Unclassified).

A particular model satellite is picked to represent a general synchronous equatorial orbit communication satellite. Consideration is first given to the motion of the undamped satellite, and then these motions are compared to those resulting from a similar satellite using solar sail attitude stabilization. Specific cases are considered, covering possible cases from a satellite with error sensing about one axis over a nonrotating Earth to the most general case of three-axis error sensing with motion about a rotating Earth. Results show that this is a practical method of effective satellite attitude control.

988. Rand Corporation, Santa Monica, California, AN INTRODUCTION TO THE APPLICATION OF DYNAMIC PROGRAMMING TO LINEAR CONTROL SYSTEMS by F. T. Smith, February 1963, RM-3526-PR, X63-11538, Contract AF-49 (638)-700 (Unclassified).

Not abstracted.

989. Reiger, S. H., COMMERCIAL SATELLITE SYSTEMS, <u>Astronautics and Aerospace Engineers</u>, Vol. 1, September 1963, pp. 26-30.

Not abstracted.

990. Rome Air Development Center, Griffiss Air Force Base, New York, A METHOD FOR CONTROLLING THE ATTITUDE OF A SATELLITE USING THE EARTH'S MAGNETIC FIELD by W. J. Minkus, September 1964, TDR-64-394, AD-614 652 (Unclassified).

This report investigates a means of controlling the attitude of a satellite in a circular orbit about the Earth by the torque

due to the interaction between the Earth's magnetic field and the magnetic moments produced by currents in three orthogonal coils aboard the satellite. This system has the advantage over more conventional ones in that no mass is expended in the control process. It is designed to rotate the satellite about its longitudinal axis in a minimum amount of time while limiting the deviation of this axis from the local normal to the Earth. The analysis is limited to the period during which the satellite's attitude is being changed by magnetically produced torques, when these torques are not applied, gravity-gradient effects act as a restoring force to align the longitudinal axis with the local normal to the Earth. The method is applicable to a satellite with symmetry such that the moment of inertia about its longitudinal axis is much smaller than those about body-fixed axes lying in a plane perpendicular to it and whose moments of inertia about axes in this plane are approximately equal. The model of the Earth's magnetic field, that is used, is a dipole with its poles located at the observed geographical positions. The control system is developed to be applicable to the general type of satellite indicated above and to all orbits except those passing close to the magnetic poles.

991. Royal Aircraft Establishment, Farnborough, England, AN ACTIVE ATTITUDE CONTROL SYSTEM FOR COMMUNICATION SATELLITES by J. K. Abbott, May 1963, Technical Note No. Space 34, AD-415 189 (Unclassified).

An active system of satellite attitude control is suggested. An example, the design, is discussed for a particular application. The system is suitable without modification for each of the control phases, acquisition, orbit adjustment, and long term control.

992. Royal Aircraft Establishment, Farnborough, England, A SUGGESTED DESIGN FOR A SATELLITE FOR STELLAR ULTRAVIOLET SPECTROMETRY by A. G. Earl, G. W. Stark, H. J. H. Sketch, G. W. Brown, G. C. Sudbury, March 1963, AD-412 364 (Unclassified).

The requirements of a satellite to be used for measuring the ultraviolet spectra of selected stars are discussed. Possible solutions to the design problems are outlined and a detailed description given of the design which is considered to be the most promising.

993. Royal Aircraft Establishment, Farnborough, England, PERTURBATIONS OF A GEOSTATIONARY SATELLITE. 1. THE ELLIPTICITY OF THE EQUATOR by R. R. Allan, July 1963, Technical Note No. Space 43 (Unclassified).

The motion in longitude of a nominally geostationary satellite due to the tesseral harmonics in the Earth's gravitational field is studied. The necessary formulas for the motion, and the corrective impulses, etc., have been developed for the principal $J_{2,2}$ term.

994. Royal Aircraft Establishment, Farnborough, England, SOME ASPECTS OF MOMENTUM-EXCHANGE SATELLITE ATTITUDE CONTROL TECHNOLOGY (VISIT TO USA, DECEMBER 1961) (U) by W. G. Hughes and W. A. Ware, TN-S44, AD-346 455 (Confidential).

Not abstracted.

995. Royal Aircraft Establishment, Farnborough, England, THE ACQUISITION OF SUN POINTING ATTITUDE BY SPACE VEHICLES WITHOUT THE USE OF RATE GYROSCOPES, TECHNICAL REPORT by J. K. Abbott, May 1965, TR-65097, AD-466 584 (Unclassified).

An attempt is made to define the initial conditions from which a sun pointing satellite with a simple "on-off" jet control system is capable of acquiring attitude control. The control system was assumed to be established by means of phase advance of the error signal rather than by the use of rate gyros.

The study was carried out mainly by digital computation. The maximum initial angular velocity from which satisfactory acquisition performance could be achieved increased with increasing available angular acceleration and fell as the inertia configuration was made more unsymmetrical. The results are strictly applicable only to control systems of the type outlined above. Suggestions are made of alternative arrangements which might be worth study.

996. Savet, P. H., ATTITUDE CONTROL OF ORBITING SATELLITES AT HIGH ECCENTRICITY, ARS Journal, Vol. 32, October 1962, pp. 1577-1582.

Not abstracted.

997. Scott, E. D.,
CONTROL MOMENT GYRO GRAVITY STABILIZATION, Progress in Astronautics and Aeronautics, Vol. 13, 1964, pp. 103-148.

Attitude control devices used to dampen vehicle librations are single-degree-of-freedom integrating gyros, called control moment gyros (CMG), which control vehicle to orbital reference established by Earth-to-satellite radius vector and orbital angular momentum vector, design parameters, CMG control system is optimized, using Monte Carlo techniques, and results of optimization are shown; optimization technique and its utility; linearization techniques, their limitations, and example showing where linearization can produce serious errors in system analysis.

998. Sklar, S. J.,
PERTURBATION ANALYSIS FOR ORBITAL ATTITUDE CONTROL, Space/Aeronautics, Vol. 38, November 1962, 83 pp.

Not abstracted.

999. Space Technology Laboratories, Inc.,
REACTION WHEEL ATTITUDE CONTROL FOR SPACE VEHICLES by R. W. Froelich, 30 August 1959, STL-TN-59-0000-00320, Pt. 2 (Unclassified).

Recent studies conducted on methods of stabilizing space vehicles have shown promise for an active control system employing reaction wheels in conjunction with an auxiliary gas system. This paper describes laboratory studies which have been conducted to determine the feasibility and practicality of a typical satellite reaction wheel control system.

1000. Space Technology Laboratories, Inc.
TECHNIQUES FOR ANALYSIS OF NONLINEAR ATTITUDE CONTROL SYSTEMS FOR SPACE VEHICLES. VOLUME I - CHARACTERISTICS OF THE SPACECRAFT ATTITUDE CONTROL PROBLEM by E. I. Ergin, June 1962, AD-282 705, ASD-TDR-62-208, Contract AF-33(616)-7811.

This report was prepared to compile, describe, and apply the available nonlinear analysis and design techniques for space vehicle attitude control systems. Volume I is a definition and description of the problems associated with the design of space vehicle attitude control systems.

1001. Sperry Gyroscope Company, Vickers, Inc.,
ORBITAL LAUNCH OPERATIONS VOLUME IV - ATTITUDE CONTROL, January 1962, AB-1210-0004-4 (Unclassified).

This report presents the results of preliminary study of attitude-control requirements for the vehicles to be used in Orbital Launch Operations (OLO). The study was conducted with the objectives of synthesizing candidate attitude-control systems for each OLO vehicle, of isolating the basic attitude-control problems peculiar to OLO, and of recommending programs that will resolve the problems and produce equipment designs suitable to the applications.

1002. Sturgeon, C W.,
SATELLITES, ARTIFICIAL—CONTROL—ON-BOARD CONTROL OF OAO SATELLITE, ISA Journal, Vol. 10, June 1963, pp. 61-64.

Not abstracted.

1003. Taylor, H. L.,
SATELLITE ORIENTATION BY INERTIAL TECHNIQUES, Journal of Aerospace Sciences, Vol. 28, June 1961, pp. 493-499.

Not abstracted.

1004. Thomas, L. C. and Cappellari, J. O.,
ATTITUDE DETERMINATION AND PREDICTION OF SPIN-STABILIZED SATELLITES, Bell System Technical Journal (USA), Vol. 43, Pt. 2, July 1964, pp. 1657-1726.

Techniques for both attitude determination and prediction for spin-stabilized satellites are developed. Their use is demonstrated using Telstar I and II satellite data. It is shown that an inclined dipole model of the Earth's magnetic field and the method of averaging the gravitational and magnetic torques over each anomalistic period of the satellite permits attitude predictions to within a few tenths of a degree of determined values in most instances. In those few cases where departures are above one degree, explanations are presented to show the reason for such discrepancies. The usefulness of combining optical flash and solar sensor data for attitude determination and their inherent accuracy are demonstrated. Optical flash data can provide loci with a resolution of 0.1 degree. Solar sensor loci are resolved to within one degree. All techniques described have been consolidated into working computer program

which follow closely the mathematical analysis presented. A number of important supporting calculations such as the solar position, sidereal time, orbit updating, etc., are also developed. Because of the complexities of the mean torque and gyroscopic equations, the precessional techniques presented are most useful in computer embodiments.

1005. Thomson, W. T.,
STABILITY OF SINGLE AXIS GYROS IN A CIRCULAR ORBIT, AIAA Journal, Vol. 1, July 1963, pp. 1556-1559.

Not abstracted.

1006. Tobias, I. I. and Kosson, R. L.,
ARC-JET PROPULSION FOR ATTITUDE AND ORBIT CONTROL OF MORL, Journal of Spacecraft and Rockets, Vol. 2, No. 5, September-October 1965, pp. 724-730.

Study of manned orbiting research laboratory (MORL) is based on mass estimates for subsystems necessary for a one-year mission in circular orbit at altitude of 200 nautical miles. Total impulse is based upon continuous thrust requirement of 0.10 pound frozen. Electrical energy required is supplied by a photovoltaic system. Hydrogen is a recommended propellant. With 14 engines, total mass of an arc-jet system is approximately 7258 pounds maximum. By comparison, stored-chemical propulsion system with specific impulse of 300 seconds has a mass of 11,790 pounds maximum; this represents launch mass saving of 38 percent for arc-jet system.

1007. Toronto University, Ontario, Canada,
DYNAMICS OF GRAVITY-ORIENTED ORBITING SYSTEMS WITH APPLICATION TO PASSIVE STABILIZATION by B. Etkin, March 1964, AFOSR 222 63, AFOSR 64 2128, AD-452 027 (Unclassified).

A theoretical framework is presented for analyzing the motion of a multibody satellite system in a gravity-oriented orbiting reference frame. It consists essentially of expressions for the forces and moments of the body-force field on arbitrary bodies and of their utilization in Lagrange's equation to find the equations of motion. It is then applied to the analysis of a specific system designed for passive attitude stabilization, the equations are linearized and separated into two groups (longitudinal and lateral), and numerical solutions are obtained.

Damping to half-amplitude in times of the order of 0.3 orbit is possible in either system separately. For combined three-axis stabilization, somewhat longer times would result from inevitable compromises. The effect of solar radiation on the system is briefly discussed.

1008. Ule, L. A.
ORIENTATION OF SHIPPING SATELLITES BY RADIATION PRESSURE, AIAA Journal, Vol. 1, July 1963, pp. 1575-1578.

Not abstracted.

1009. Valley Forge Space Technology Center, Philadelphia, Pennsylvania,
COMMUNICATIONS SATELLITE PROJECT ADVENT, QUARTERLY PROGRESS REPORT NO. 1, 1 JUNE-31 AUGUST 1962, September 1962, DN62SD4302, AD-452 220, Contract AF-04(647)-476 (Unclassified).

CONTENTS

Environmental Tests-Flight Proof Vibration Tests

Thermal-Vacuum Test

Performance Tests-Propulsion and Attitude Control Tests

Electric Power Subsystem Test, and Solar Module Tests

Ground Station and Fly-By Ground Satellite TTC Simulators and Fly-By Satellite TTC Simulators

Orbit Command and Control

Reliability.

1010. Valley Forge Space Technology Center, Philadelphia, Pennsylvania,
COMPUTER SIMULATION OF THE ADVENT THREE AXIS ATTITUDE CONTROL SYSTEM IN THE NORMAL OPERATIONAL MODE by D. G. Barringer, M. F. Garrity, and J. D. Selby, October 1962, 62SD4309, AD-453 876, Contract AF-04(647)-476 (Unclassified).

This report contains the equations of motion and the sensor equations, with derivations, for the ADVENT vehicle. It is intended to show the equations which were programmed for the three-axis simulation on an analog computer and also the

results of that simulation. Since initial stabilization was the subject of a separate report, the vehicle is assumed to be in a normal mode of operation. This report contains an investigation of the effects of disturbances, coupling, system parameter variations, and system response during the high noon and dark period reorientations. It also contains the derivation of equations, discussion of results, and a table showing a complete list of the computer runs that have been made. Phase plane trajectories, selected brush traces, computer diagram, and system simulation block diagram are also included.

1011. Vinson, P. W.,
EXTENSION OF REACTION CONTROL EFFECTIVENESS CRITERIA TO MACH 10; EXPERIMENT AND THEORY, AIAA Journal, Vol. 3, March 1965, pp. 536-537.

Not abstracted.

1012. Voas, R. B.,
MANUAL CONTROL OF MERCURY SPACECRAFT, Astronautics, Vol. 7, No. 3, March 1962, pp. 18-20, 34, 36, 38.

Pilot may take full control over attitude of vehicle any time from separation of booster through orbital flight, retrofire, and reentry. Four tasks facing the astronaut are control of attitude in orbit, during retrofire, rate damping during reentry, and recovery from tumbling maneuvers. The most critical maneuver is controlling the vehicle during retrorocket firing.

1013. Westinghouse Defense and Space Center, Aerospace Division, Baltimore, Maryland,
GROUND CONTROL OF ADVANCED SPACE VEHICLE, FINAL REPORT FOR 15 MAY 1964 - 30 JUNE 1965 by J. Braumiller, J. Miller, L. Hart, H. Dittmar, and H. Alatalo, September 1965, TR-65-255, AD-622 812, Contract AF-30(602)-3386 (Unclassified).

The feasibility is explored of controlling the orbits and orbit positions of satellites of large area-to-mass ratio by radiation pressure. An orbit maneuvering technique was specified that would enable control of the relative spacings of a group of satellites, including equally distributed placement from a single launcher and subsequent routine corrections.

Control is effected by occasional rotations about one axis to change the angle of a surface pattern relative to the velocity vector. The pattern is a sail with reflectivities on its two sides different. A system for determining optimum commands and command times for a group of satellites was determined. Performance of the method was evaluated for a variety of satellite sizes, altitudes, orbit inclinations, orbit eccentricities, and other parameters.

A functional plan was prepared for the single ground station which controls the system. The attitude control of an antenna pointing satellite was studied.

This communications satellite is required to aim toward two or more points on Earth in succession.

One or both points may be capable of transmitting, and sensing schemes have been developed for both cases. The accuracy and dynamic performance of a reaction wheel torquing system has proven satisfactory in digital computer simulations.

1014. Whitford, R. K.,
ATTITUDE CONTROL OF EARTH SATELLITES. I. SOURCES OF TORQUE, Control Engineering (USA), Vol. 9, No. 2, February 1962, pp. 93-97.

Early satellites were spin stabilized, but this alone does not provide adequate control for the most modern satellites. The effects of spin stabilization, solar radiation pressure, gravity gradient, the Earth's magnetic field, and aerodynamic torques are considered both from their effects as disturbing influences and as sources which can be harnessed for control. The uses of momentum storage, proportional mass expulsion, and combinations of both for the attitude control of satellites are briefly described. No single method of control is ideal for every purpose, so the designer must examine all the possibilities and select the most suitable method for his particular requirements.

1015. Wolfe, R. R.,
ENERGY REQUIREMENTS FOR SATELLITE STABILIZATION OF THE GRAVITATIONAL GRADIENT, ARS Journal, Vol. 31, June 1961, pp. 836-838.

Not abstracted.

1016. Zajac, E. E.,
CAPTURE PROBLEM IN GRAVITATIONAL ATTITUDE CONTROL OF SATELLITES, ARS Journal, Vol. 31, October 1961, pp. 1464-1466.

Not abstracted.

1017. Zajac, E. E.,
LIMITS ON THE DAMPING OF TWO-BODY GRAVITATIONALLY ORIENTED SATELLITES, AIAA Journal, Vol. 1, February 1963, pp. 498-500.

Not abstracted.

1018. Zajac, E. E.,
TWO-GYRO, GRAVITY-GRADIENT SATELLITE ATTITUDE CONTROL SYSTEM, Bell Telephone System Technical Journal, Vol. 43, November 1964, pp. 2705-2765.

Not abstracted.

4. Optimization

1019. Aerospace Corporation, El Segundo, California,
ORBIT TRANSFER AND RENDEZVOUS MANEUVERS BETWEEN INCLINED CIRCULAR ORBITS, TECHNICAL OPERATING REPORT by J. M. Baker, June 1965, TR-65-76, TDR-469 (5540-10)-11, AD-466 843, Contract AF-02(695)-469 (Unclassified).

Several orbit transfer and rendezvous maneuvers between inclined circular orbits, including the Bielliptic transfer with plane change, the Hohmann transfer with plane change, and the "modified" Hohmann transfer are discussed in this report. The "modified" Hohmann transfer is a rendezous maneuver consisting of an in-plane Hohmann transfer to the final radius, followed by a third impulse at the line of nodes to change the interceptor's plane to that of the target. The total delta V requirements are given in terms of final-to-initial radius ratio for various plane change angles. The optimum plane change split for both the Bielliptic and the Hohmann maneuvers is shown. The delta V savings over making all of the plane change at the largest radius are indicated. The phasing angles and the rendezvous times are evaluated, and the regions where the

Bielliptic maneuver is either faster or requires less total delta V than the "modified" Hohmann transfer are indicated. Due to the extremely long waiting time to obtain the correct phasing, the Hohmann transfer with plane change maneuver would not be used for rendezvous.

1020. Air Force Systems Command, Foreign Technology Division, Wright-Patterson Air Force Base, Ohio,
CERTAIN PROBLEMS OF OPTIMUM CONTROL OF THREE DIMENSIONAL MOTION OF SPACE VEHICLES by R. V. Studnev, May 1965, FTD-MT-65-120, TT 65-62377, AD-615 854 (Unclassified).

In this report, there are investigated questions of optimum pulse control of the spatial orientation of an axially symmetric space vehicle (SV). It is assumed that control of the SV is carried out by two pairs of control jets (CJ), one of which is fastened in the vehicle and creates a moment about the axis of symmetry, and the second pair is fixed in a cardan suspension and can create a moment about any axis orthogonal to the axis of symmetry of the apparatus. Optimum control of orientation of the axis of rotation which is the axis of symmetry of the SV is found. Conditions are determined under which control of orientation can be carried out by one pair of CJ fastened in the vehicle, control is optimized of orientation of the SV rotating about a principal axis of inertia which is not the axis of symmetry. Optimum control of the spatial orientation of an axially symmetric SV is investigated in general.

1021. Aseltine, J. A.,
APPLICATION OF OPTIMAL CONTROL TECHNIQUES TO THE SPACE GUIDANCE PROBLEM, International Symposium on Space Technology and Science, 5th, Tokyo, Japan, 2-7 September 1963, Proceedings, 1964, pp. 843-850 (A65-14290 A65-14356).

This article presents a review of several methods of synthesizing optimal control systems, and application of each of them is a problem of space guidance. The methods reviewed are:

1) The classical calculus of variations.
2) The Pontryagin maximum principle.
3) Bellman's dynamic programming.

The methods are applied to the problem of determining the trajectory which will maximize the altitude at which a satellite

is injected into orbit. The results of the application of these methods are compared, and their possible use in practical guidance systems is discussed. It is concluded that, of the methods considered for the solution of the optimum trajectory, the method of Pontryagin seems to offer the most in terms of implementation. A block diagram of a possible method to provide guidance for satellite injection is shown in this article.

1022. Born, D. C.,
CONTROL CRITERIA FOR MANUAL ORBITAL RENDEZVOUS, Advances in the Astronautical Sciences, Vol. 16, Pt. 1. Space Rendezvous, Rescue, and Recovery, North Hollywood, California, Western Periodicals Co., 1963, pp. 174-198 (USAF and American Astronautical Society, Space Rendezvous, Rescue, and Recovery, Symposium, Edwards Air Force Base, California, 10-12 September 1963), A63-25753.

This article presents some consideration of the advantages of displaying navigation data in the form of "control criteria" which involve the specification of thrust and vehicle attitude requirements, as an aid in the manual control of orbital rendezvous. Data displayed in this manner are shown to expedite quasi-optimal manual control for the random variety of initial target-chaser relative conditions which occur because of prior guidance errors. Control criteria requiring a minimum of predisplay computation, and resulting in simple cockpit displays, are developed for different types of rendezvous translation propulsion systems.

1023. California Institute of Technology, Jet Propulsion Laboratory, Pasadena, California,
A DYNAMIC PROGRAMMING ANALYSIS OF MULTIPLE GUIDANCE CORRECTIONS OF A TRAJECTORY by C. G. Pfeiffer, 15 November 1963, NASA CR-53000, JPL-TR-32-513, N64-13281, Contract NAS7-100 (Unclassified).

In this report, the problem of deciding when to apply guidance corrections to the perturbed trajectory of a spacecraft is treated from the dynamic programming point of view. It is assumed that the objective of the guidance correction policy is to minimize the expected value of the squared error at the final time, subject to the constraint that the total correction capability expended be less than some specified value. It is shown that a correction should be performed when a certain "switching function" passes through zero. Assuming that the orbit determination procedure has been prespecified, and that

the statistics of the correction errors are known, the switching function is found to depend upon the instantaneous state of the system, which is composed of the following:

1) The estimate of the trajectory perturbation to be corrected.
2) The variance of the error in this estimate.
3) The correction capability of the spacecraft.

Equations for computing the switching function are derived, and a numerical example is presented in this report.

1024. DeMarinis, L. and Huttenlocher, H., Jr., OPTIMIZING INERTIAL REACTION WHEELS FOR SPACECRAFT SLEWING AND ATTITUDE CONTROL, IEEE Transactions on Aerospace (USA), Vol. AS-2, No. 2, April 1964, pp. 444-451 (Aerospace Electro-Technology Conference, Phoenix, 1964).

This article deals primarily with a technique for designing and optimizing a slewing (re-orientation) inertia wheel. The approach, although patterned around NASA's Orbiting Astronomical Observatory, is general and can be tailored to meet the requirements of most spacecraft utilizing inertial wheels for changing their orientation. A method for slewing the spacecraft is briefly discussed, and it is shown how the parameters required to design the inertia wheel affect the final design. The interdependence of other spacecraft subsystems on the optimum inertia wheel design is stressed. Starting with the expression for the theoretical speed-torque curve of the motor, a set of equations are developed for the design optimization of the parameters for an open-loop inertia wheel system. It is the goal of the optimizing technique presented to determine the optimum relationship between weight and power consumption.

1025. Gass, S. I., Scott, M. B., Hoffman, R., Green, W. K., Peckar, A., Peavey, R. D., and Hamlin, J. E., PROJECT MERCURY REAL-TIME COMPUTATIONAL AND DATA-FLOW SYSTEM, Eastern Joint Computer Conference, Proceedings, Vol. 20, 1961, pp. 38-78.

This article discusses the role of digital computers in Project Mercury as an integral part of real-time decision-making complex to process observations made in launch,

orbit, and reentry phases and to supply continuous, up-to-date records of the nonenvironmental status of the spacecraft. Programming system, real-time simulation, and Mercury launch monitor subsystem are included.

1026. General Electric Company, Schenectady, New York, STUDY OF SATELLITE ATTITUDE CONTROL AND RELATED ENERGY SOURCES, FINAL REPORT by A. C. Nichol and L. R. Wood, May 1963, TDR-63 179, AD-409 957, Contract AF-33(657)-7717 (Unclassified).

This report summarizes the research and development studies of Earth orbiting vehicle attitude control and stabilization systems and their related power sources. These studies were undertaken to formulate design, performance, and equipment application criteria for use in synthesizing optimal attitude control systems for satisfying future vehicle requirements. The parameters of primary concern included accuracy, performance, dynamic response, energy expenditure, complexity, weight, and reliability.

1027. Gobetz, F. W., A LINEAR THEORY OF OPTIMUM LOW-THRUST RENDEZVOUS TRAJECTORIES, Journal of the Astronautical Sciences, Vol. 12, 1965, pp. 69-76 (A66-13457, Contract NAS8-11099).

A complete analytic solution is presented for linearized, optimum, variable-thrust rendezvous trajectories with power-limited propulsion systems. The theory is developed in three dimensions in terms of planetary variables, thus avoiding singularities for zero eccentricity and zero inclination. Numerical comparisons with exact data are presented for Earth-Mars and Earth-Venus rendezvous trajectories with correlations for optimum steering programs, trajectories, and fuel consumption.

1028. Gobetz, F. W., OPTIMAL VARIABLE-THRUST TRANSFER OF POWER-LIMITED ROCKET BETWEEN NEIGHBORING CIRCULAR ORBITS, AIAA Journal, Vol. 2, No. 2, February 1964, pp. 339-343.

Minimum-fuel transfers between neighboring circular orbits for low-thrust propulsion systems are studied. Analysis is based on simplification that only small deviations from

original circular orbit are allowed, so that gravitational terms in equations of motion may be linearized. Completely analytical solution is determined, and resultant thrust-vector control programs are compared with those obtained previously by H. K. Hinz for constant-thrust acceleration.

1029. Greenley, R. R.,
COMMENTS ON "THE ADJOINT METHOD AND ITS APPLICATION TO TRAJECTORY OPTIMIZATION," AIAA Journal, Vol. 1, June 1963, p. 1463 (A63-18010).

Criticism of the solutions obtained by Jurovics and McIntyre on the problem of a minimum time transfer between two coplanar orbits assuming a constant thrust acceleration has been made. The solution presented appears to be erroneous.

1030. Luidens, R. W.,
APPROXIMATE ANALYSIS OF ATMOSPHERIC ENTRY CORRIDORS AND ANGLES, NASA Technical Note D-590, January 1961.

Simple closed-form approximate solution is developed for corridor depths and entry angles as function of maximum g load, initial entry velocity, and configuration lift drag ratio for vehicles operating at constant and modulated angle of attack. Vehicle design and mode of operation that result in deepest corridors are determined, and effects of hot gas radiation and limiting Reynolds number on corridor depth are discussed.

1031. Massachusetts Institute of Technology, Cambridge, Massachusetts,
A VARIATIONAL CALCULUS SOLUTION TO THE OPTIMUM ORBITAL ESCAPE PROBLEM AND COMPARISON WITH SEVERAL STEERING PROGRAMS OF SIMPLE ANALYTICAL FORM, MASTER'S THESIS by L. A. Baron, June 1961, AFOSR 1008. AD-613 357, Contract AF-49(638)-363 (Unclassified).

The calculus of variations is used to determine the power level, thrust magnitude, and steering program which will minimize the propellant necessary for a vehicle to effect an escape from an orbit around the Earth. The trajectory is shown to consist of a number of thrusting subarcs proportional to the value of the time constraint. If the time constraint is

less than one revolution of the initial orbit, the trajectory consists of one thrusting arc. For a thrust-limited vehicle, it is shown on physical grounds that the thrusting arc consists of maximum thrust. For a power-limited vehicle, the variational apparatus yields a maximum power, maximum specific impulse thrusting arc. The optimum steering program determined numerically through the use of a digital computer is found to begin slightly below the horizontal and increases until the thrust direction is exactly aligned with the velocity vector at the terminal point. Several steering programs of a simple analytical form are also computed numerically for a comparison with the optimum program.

1032. Massachusetts Institute of Technology, Electronic Systems Laboratory, Cambridge, Massachusetts,
A STUDY OF COORDINATE-CONVERSION ERRORS IN STRAPPED-DOWN NAVIGATION by F. B. Hills, ESL-R-244, AD-474 118, X66-12439, Contract AF-33(657)-11311 (Unclassified).

Not abstracted.

1033. Massachusetts Institute of Technology, Experimental Astronomy Laboratory, Cambridge, Massachusetts,
ANALYTIC SOLUTION OF THE EQUATIONS OF MOTION OF AN INTERPLANETARY SPACE VEHICLE IN THE MID-COURSE PHASE OF ITS FLIGHT by R. G. Stern, November 1963, NASA CR-53469, RE-4, N64 18170, NASA Grant NsG-254-62 (Unclassified).

Linear perturbation theory is used to define the actual path of the vehicle relative to the elliptical reference path. The equations of motion for the actual path constitute a sixth-order linear system with variable coefficients. Two methods are presented for solving this system analytically to yield the variations in position and velocity as a continuous function of time. The first solution exploits the fact that variations in the reference trajectory plane are uncoupled from variations normal to the plane. Thus, by the choice of a coordinate system in which one of the three orthogonal axes is perpendicular to the reference trajectory plane, the sixth-order system is separated into two independent systems, one of fourth order and one of second order. The second method of solution utilizes the fact that the actual trajectory, like the reference trajectory, is an ellipse, but the orbital elements of the two

ellipses are not identical. Linear theory is used to determine variations in position and velocity as a function of variations in the six orbital elements.

1034. Meditch, J. S.,
ON MINIMAL FUEL SATELLITE ATTITUDE CONTROLS, Joint Automatic Control Conference, 19-21 June 1963, pp. 558-564.

Control time and quantity of fuel are treated as parameters to develop a set of performance limitations for minimal fuel single axis attitude control of space vehicle.

1035. Nelson, W. L.,
ON THE USE OF OPTIMIZATION THEORY FOR PRACTICAL CONTROL SYSTEM DESIGN, IEEE Transactions on Automatic Control (USA), Vol. AC-9, No. 4, October 1964, pp. 469-476.

The approach to control system design discussed in this paper has as its purpose the more effective utilization of optimal control theory for the development and the evaluation of practical system designs. Rather than specifying initially a single performance index (or an arbitrary scalar function of several indices), the performance bounds relating the various competing performance requirements of the system are first evaluated using optimization techniques, so that the ultimate trade-offs achievable between these requirements are well understood. These performance bounds then form the basis not only for a more meaningful specification of optimum system performance but also for the evaluation of suboptimal designs which are developed from approximations of the optimal control strategies, from previous designs, and from the experience and insight of the designer. The specific example of the satellite attitude control problem is used to illustrate this design approach. Performance bounds between control fuel expenditure and control time are obtained over a range of initial conditions. Using this information and the knowledge of the form of the minimum-fuel control law, a simple feedback control design is developed which is superior to either the well-known minimum-time or the minimum-fuel solutions, both from the point of view of achieving on-the-bound performance which represents the best compromise between these competing performance requirements and from the point of view of practical implementation. The final portion of this

paper describes the computer-aided design program which has been undertaken to extend this design approach to more complex control problems.

1036. O'Brien, R. M. and Sievers, R. F., OPTIMIZATION OF GUIDANCE LAWS TO ACHIEVE ORBITAL RENDEZVOUS WITH A PROPULSION SYSTEM OF ONLY MODERATE THROTTLABILITY, American Institute of Aeronautics and Astronautics, 1965, pp. 270-277 (In: AIAA/ION GUIDANCE AND CONTROL CONFERENCE, MINNEAPOLIS, MINNESOTA, 16-18 AUGUST 1965, A66-10001, A66-10027).

This article presents a study of the rendezvous and docking maneuvers necessary to assemble an Earth-escape configuration for a manned interplanetary mission. Terminal guidance equation parameters are optimized for a rendezvous homing mission and a combined homing-docking mission. The criterion $a_c = a_n$ is seen to produce superior performance when applied as a thrust initiation criterion for rendezvous maneuvers. As a consequence, the mission could be achieved with a propulsion system providing a nominal thrust acceleration of as much as 4 ft/sec^2 for the most perturbed transfer orbit. A guidance equation was developed for providing a smooth transition between homing and docking. The docking maneuver requires approximately the same amount of fuel as a homing mission, but about 5 to 10 percent more throttling capability.

1037. Rand Corporation, A COMPUTATIONAL TECHNIQUE FOR OPTIMAL CONTROL PROBLEMS WITH STATE VARIABLE CONSTRAINT by Y. C. Ho, March 1962, Rand RM-3042-NASA, NASr-21(02), NONr-1866(16) (Unclassified).

This report describes a general computational procedure that may be applied to optimizing the performance of a dynamic system subject to a certain restriction; for example, the procedure might be applied to optimizing the trajectory flown by a space vehicle, subject to the restriction that the mass of the fuel consumed did not exceed a certain value. The procedure is based on successive approximations which converge toward the desired solution.

1038. Republic Aviation Corporation,
COMPARISON OF SPECIAL PERTURBATION METHODS IN CELESTIAL MECHANICS by S. Pines, M. Payne, and H. Wolf, March 1960, ARL TR-60-281, Contract AF-33(616)-6449 (Unclassified).

The object of the investigation is to critically compare commonly used numerical methods for orbit computation. From the many methods available, the following three were chosen:

1) Cowell's method.
2) Encke's method.
3) Method of variation of parameters.

Instead of comparing the methods against each other, with the attendant difficulty in deciding which of differing results is the more accurate, they were all compared with an exact solution of the problem of two fixed centers of gravitation. These three methods and the exact solution are described in this report.

1039. Republic Aviation Corporation,
COMPARISON OF SPECIAL PERTURBATION METHODS IN CELESTIAL MECHANICS by S. Pines, M. Payne, and H. Wolf, August 1960, ARL TR-60-28, Contract AF-33(616)-6449 (Unclassified).

The object of the investigation is to critically compare commonly used numerical methods for orbit computation. From the many methods available, the following three were chosen:

1) Cowell's method.
2) Encke's method.
3) Method of variation of parameters.

Instead of comparing the methods against each other, with the attendant difficulty in deciding which of differing results is the more accurate, they were all compared with an exact solution of the problem of two fixed centers of gravitation. These three methods and the exact solution are described in the Sections II and III of this report. The results of the comparison, given in Section IV, lead clearly to the conclusion that the Encke method is superior in all respects

to the other two for a problem in which the classical two-body problem is locally a good approximation. For other problems, a modification of this method is indicated, rather than use of the Cowell method or the variation of parameters method.

1040. Schmieder, D. H.,
USE OF CALCULUS OF VARIATIONS METHODS FOR TRAJECTORY OPTIMIZATION AND ADVANCED GUIDANCE CONCEPTS, WGL Tagung, Freiburg im Breisgau, Germany, 10-13 October 1961 (In: Wissenschaftliche Gesellschaft für Luftfahrt E. V., Jahrbuch, 1961, Braunschweig, Friedr. Vieweg and Sohn, 1962, pp. 272-277, A63-21855).

This article discusses the trajectory design and guidance of rocket-propelled vehicles. Calculus of variation methods are described as used in the more refined trajectory optimization and guidance modes demanded by the large vehicles which must economically accomplish a variety of space missions.

1041. University of Southern California, Department of Electrical Engineering, Los Angeles, California,
DISCRETE TERMINAL CONTROL OF SPACE VEHICLES VIA MATHEMATICAL PROGRAMMING, INTERIM TECHNICAL REPORT by N. E. Nahi and L. A. Wheeler, October 1965 (USCEE-141, SSD-TR-65-130, AD-473 177, X66-12478, Contract AF-04(695)-746) (Unclassified).

The control objective of some systems is to obtain the minimum value for a function of the state of the system at a specified time in the future, starting from a given initial condition. For example, in the rendezvous mission for two space vehicles during the midcourse guidance phase, the states of the vehicles are to be brought as close together as possible at the time when terminal control is to be initiated. The measure of closeness will then be a function of the positions, velocities, accelerations, etc., at the terminal time of the midcourse guidance. The above problem for the case of linear plants has been formulated in terms of mathematical programming concepts. An efficient computational algorithm is introduced where the properties of the reachable sets in state space have been used to advantage. Two examples of reasonably complex systems (three poles and one zero in the transfer function of the plant) are given to illustrate the feasibility of the algorithm in terms of practical systems.

1042. Abate, J. E.,
STARTRACKING AND SCANNING SYSTEMS, THEIR PERFORMANCE AND PARAMETRIC DESIGN, IEEE Transactions on Aerospace Navigational Electronics (USA), Vol. ANE-10, No. 3, September 1963, pp. 171-181.

This paper deals with startracking and scanning systems whose utlimate application is the navigation and control of aerospace vehicles. The subject generally has received very sparse treatment in the open literature. This paper discusses some of the critical considerations related to the optimum design and performance of startrackers and scanners. It discusses the basic system and its functional elements, input data, characteristics and performance, photomultiplier and vidicon as promising radiation detectors, decision problem and its probabilistic nature, and optimization of system performance through the manipulation of major design parameters.

1043. Abate, J. E.,
STARTRACKING AND SCANNING SYSTEMS, THEIR PERFORMANCE AND PARAMETRIC DESIGN, IRE International Convention Record (USA), Vol. 9, Pt. 5, 1961, pp. 3-15.

The systems described are for the control and navigation of aerospace vehicles. The basic factors determining the design of a system capable of first scanning until a target is found and then tracking on this target are studied. The most sensitive detectors are photomultipliers and photoconductive devices such as the vidicon-the special advantages of each are discussed. Design data are given in the form of tables and graphs.

1044. Abate, J. E.,
THE NATURE OF ASTRO DOPPLER VELOCITY MEASUREMENT, IRE Transactions on Space Electronics and Telemetry (USA), Vol. SET-8, No. 1, March 1962, pp. 50-56.

This paper discusses astro Doppler velocity measurement for space vehicle navigation. The measurement yields the relative velocity of the vehicle with respect to a star,

and requires the use of electro-optical systems capable of measuring a small incremental change in the wavelength of propagated stellar energy. Such systems provide velocity data whose character and limitations are a function of the star's spectral radiation as well as the system instrumentation. This paper discusses the astro velocity data, its derivation, character, and limitations; and the Doppler velocity systems, their capabilities, limitations, and possible instrumentation.

1045. Albus, J. S. and Schaefer, D. H.,
SATELLITE ATTITUDE DETERMINATION: DIGITAL SENSING AND ON-BOARD PROCESSING, IEEE Transactions on Space Electronics and Telemetry, Vol. SET-9, September 1963, pp. 71-77.

Analysis of the aspect determination problem for a rotating spacecraft that uses a digital aspect sensor is described. Such a sensor, which consists of a number of photo-duo-diodes placed behind a light mask with slit openings, is described. Opaque separators are situated between the photo-duo-diodes so that each photo-diode "sees" only the portion of the light mask directly in front of it. The attitude determination system used on the S-3 energetic particles satellite series, including the Explorer XII (1961 Upsilon 1) and Explorer XIV (1962 Beta Gamma 1), is briefly described. Results of aspect measurements on Explorer XII show an unexpected increase in spin rate due to solar pressure, and measurements on Explorer XIV indicate an erratic precession history.

1046. Arck, M. H.,
SIMULATOR PROVES OPERATION OF HORIZON SENSORS, Automatic Control, Vol. 15, No. 3, September 1961, pp. 21-23 and 26.

This article describes how infrared horizon sensors are put through their paces in the laboratory by a simulator and shows proof of their operational reliability before they are used on Project Mercury capsule.

1047. Arnesen, L.,
DEAD-RECKONING INDICATOR - BACKUP FOR MERCURY ASTRONAUTS, Space/Aeronautics, Vol. 35, No. 6, June 1961, pp. 67-69.

The Mercury capsule contains Minneapolis-Honeywell dead-reckoning "earth-path" indicator driven by spring wound clock mechanism; analysis of the theory of earth path indicator that will enable orbiting astronaut to determine position and direction of motion of vehicle by mechanical dead reckoning; and some details on unit installed.

1048. Author Unknown,
ANGULAR RATE SENSED BY RING LASER, Space/Aeronautics, Vol. 39, March 1963, p. 49.

Not abstracted.

1049. Author Unknown,
CANOPUS STAR SENSOR WILL PROVIDE METHOD TO CORRECT SURVEYOR COURSE, Missiles and Rockets, Vol. 15, No. 1, 6 July 1964, pp. 36-37.

Surveyor star sensor that will provide plane of reference for course correction 60,000 miles along unmanned spacecraft's cislunar trajectory will identify and lock onto selected star by measuring its brightness relative to the sun; midflight course correction calls for plane of reference established by two known lines of direction from spacecraft; one of these is gained by sensing sun and the second is provided by Canopus, which gives defining line nearly at right angles to sun line; operational details and signal separation.

1050. Author Unknown,
DESIGNERS SEE SPACE GUIDANCE SYSTEMS TURNING INTO MOSAICS OF OPTICAL CELLS, Electronics, Vol. 35, 6 July 1962, pp. 26-27.

Not abstracted.

1051. Author Unknown,
LASER GYRO BENDS LIGHT BEAMS AROUND A RING, Machine Design, Vol. 35, 14 March 1963, p. 12.

Not abstracted.

1052. Author Unknown,
LSI GEOCENTRIC PENDULAR CONTROL SYSTEM (Commande Pendulaire Geocentrique L.S.I.), Air Techniques, Vol. 9, September-October 1965, pp. 63-66, A66-15414 (In French).

Included is a description of a geocentric pendular control, which is a hanging gyroscope conceived for the purpose of detecting the sense of direction of the terrestrial field of attraction. It is used as an erection controller for a vertical gyro or a gyroscopic stabilization platform. In practice, the system serves to detect the error which exists between the pendulum and that vertical established by the position of the vertical gyro. This error is divided into roll and pitch components, and applies an adequate couple to the vertical gyro, in the proper direction, in order to cancel the error.

1053. Author Unknown,
LUNAR LANDING RADARS, Missiles and Space, Vol. 11, No. 2, February 1963, pp. 34-36.

Early lunar exploration will depend upon ability to soft land payload on surface of moon; radar altimeter described will provide signals to spacecraft control system for altitude and rate of descent control; it must continuously measure slant range from spacecraft to lunar surface; radar altimeter and Doppler velocity sensor are combined into one equipment; and details of system.

1054. Author Unknown,
MARINER 4 FINDS ITS GUIDING STAR, Electronics, Vol. 37, 14 December 1964, pp. 89-91.

Not abstracted.

1055. Author Unknown,
STAR-PATTERN RECOGNITION DEVICE URGED, Missiles and Rockets, Vol. 12, No. 25, 24 June 1963, pp. 48-50.

Self adaptive star-pattern recognition device for space navigation is proposed by Astropower, Inc., which could be first step toward development of Multi-Function Sensor (MFS) capable of automatically selecting safe lunar or planetary landing sites and guiding unmanned roving surface vehicles; system is based on tested "decision filter" which can identify three-dimensional shapes; for star-pattern recognition problems, 200 majority logic units are sufficient; star-pattern recognition device is simplified by using sun sensor to orient one axis of vehicle; and other features.

1056. Author Unknown,
YAGI AND A HELIX FOR TOPSI, Engineering, Vol. 197, 13 March 1964, p. 399.

Not abstracted.

1057. Autonetics, Downey, California,
ACCELEROMETERS FOR SPACE VEHICLE GUIDANCE by J. M. Slater, 1959, N64-18276 (Unclassified).

Accelerometers for space-vehicle guidance are reviewed. Specifications for accelerometer performance for the launching phase (from the Earth), the midcourse phase, and the terminal or landing phase are given. The principle advantages and disadvantages of the following types of accelerometers are discussed: (1) gyropendulum accelerometers, (2) differentiating-feedback accelerometers, (3) accelerometers with electronic integrators, and (4) variable-frequency vibrator accelerometers. Also discussed are the sources of error in accelerometers.

1058. Barnes, J. W. and Goodlet, J., Jr.,
A SILICON PHOTOVOLTAIC SENSOR FOR DAYLIGHT USE IN STAR DETECTION AND TRACKING SYSTEMS, IEEE International Convention Record (USA), Vol. 11, Pt. 5, 1963, pp. 103-110.

The design of star detection and tracking systems for navigational use generally involves bandwidth and optical parameter compromise to obtain daylight operation using a photoemissive type detector. For Daylight Star Detection it is shown that a photovoltaic silicon sensor has certain advantages when compared with the use of a photomultiplier tube. Silicon sensor parameters as related to preamplifier and system design are analyzed and discussed with respect to optimum signal-to-noise capability. A realizable technique for daylight star detection is described and supporting test data are evaluated for a surface junction silicon sensor having a particular geometry designed to eliminate background gradient signals. Prospects for improving the signal-to-noise ratio of the photovoltaic sensorpreamp combination are examined.

1059. Birnbaum, M. M. and Salomon, P. M.,
ASTROGUIDE-SPACE-VEHICLE NAVIGATION SYSTEM, IRE International Convention, Record, Vol. 10, Pt. 5, 1962, pp. 137-152.

Astroguide system consists of array of image sensors, electronics package, and computer controller; each image sensor is composed of wide angle lens and television-camera tube; by deflecting the camera-tube electron beam with direct positioning currents on which alternating current search pattern is superimposed, any small portion of total field of view can be examined in detail; and need for a gimballed platform or mechanical motion is thus eliminated.

1060. Blakemore, D. J.,
MAGNETIC TORQUING SCHEME, AIAA Journal, Vol. 1, August 1963, pp. 1888-1889.

Not abstracted.

1061. Brunelle, H. E., Jr. and Willey, R. R., Jr.,
COAXIAL, DUAL-FIELD OPTICS FOR SPACE SEXTANT, Applied Optics, Vol. 2, No. 12, December 1963, pp. 1265-1269.

Telescope having a two-degree field of view and optical system with a 165-degree inside-out, quasi-stigmatic field of view, which has been axially integrated to be mutually non-obscuring and confocal, is described; navigation and guidance application requirements of space vehicles from which optical specifications have been derived are discussed; and semi-automatic lens design program for IBM 7090 computer developed by Willey was used in optimization of optical design.

1062. Chapman, D. S. J.,
SIGNAL-TO-NOISE POWER RATIO AVAILABLE FROM PHOTOMULTIPLIERS USED AS STAR DETECTORS IN STARTRACKING SYSTEMS, A METHOD OF ASSESSMENT, Journal of British Institution of Radio Engineers, Vol. 23, No. 3, March 1962, pp. 209-216.

In space navigation, or attitude control of satellites, where guidance is effected by reference to a set of axes defined by a stabilized platform, continuous monitoring of the reference axes will be required to compensate for the inevitable long-term drift of the stabilizing gyros. Changes in the directions of distant "fixed" stars provide a convenient monitoring reference; to use such a monitoring reference, two or more startracking systems must be employed. The concept of a startracking system as (1) a direction measuring device demanding, for satisfactory operation, a minimum signal-to-noise ratio which is dependent upon certain system parameters, is briefly stated. A method of deriving an asymptotic approximation to the available signal-to-noise ratio as a function of stellar visual magnitude is described; and in deriving this asymptotic function, the relationships between a number of system parameters are clarified and given graphical significance.

1063. Collen, E.,
MANUAL CELESTIAL NAVIGATION INSTRUMENT, IRE East Coast Conference on Aerospace and Navigational Electronics - Technical Paper 1.2.6 for meeting 23-25 October 1961, 6 pp.

A small, hand-held, passive navigation device is described which permits spacecraft crewman to locate instantly his present position on model Earth globe. Special optics and visual star pattern matching method eliminate computations.

1064. Dawson, J. C. and Gamber, W. N.,
HIGH-RESOLUTION SYSTEM FOR LUNAR AND PLANETARY LANDING-SITE SELECTION, IEEE National Space Electronics Symposium, PTGSET Record, Paper 9.1, October 1963, 8 pp.

High resolution radar combined with special processor that operates on signals from parallel narrow-band receivers is proposed as means for closely examining proposed landing area for space vehicle; the system would be capable of surveying an area of 500 by 500 feet from nominal vehicle altitude of 1000 feet, in less than 30 seconds of hover time, and of determining presence of surface irregularities that vary more than three feet from average level; and smooth slopes of five degrees or more could also be determined.

1065. Deutsch, R.,
NOVEL SOLAR SYSTEM COMPASSES FOR INTERPLANETARY FLIGHT, Progress in Astronautics and Aeronautics, Vol. 13, 1964, pp. 583-600.

Included is a description of optical and radio compass; optical compass uses novel technique for establishing vehicle-sun line by accurately determining sun's apparent center; radio transmissions from artificial Earth satellite serve as Doppler frequency source from which Earth-vehicle line can be established from theory of artificial spectroscopic binary stars; combination of two compasses provides navigation system based upon time variation of angle between two directions; and system accuracies and sensitivities.

1066. Diesel, J. W., NEW APPROACH TO GRAVITATIONAL GRADIENT DETERMINATION OF THE VERTICAL, AIAA Journal, Vol. 2, July 1964, pp. 1189-1196.

Not abstracted.

1067. Eberhardt, E. H., ACCURACY OF POSITION DETERMINATION IN STAR-TRACKER TUBES, IEEE Transactions on Aerospace, Vol. AS-1, No. 2, August 1963, pp. 54-57.

Focusing properties of startracker tubes can be summarized by quantity, called rise distance, which measures sharpness of transition between light and dark areas; measurements showing values achieved to date are presented; and it is shown how shortcomings of rise distance can be overcome by proper choice of data handling process, i.e., output circuitry.

1068. Ewen Knight Corporation, East Natick, Massachusetts, MOLECULAR ATMOSPHERIC OXYGEN HORIZON STUDY RADIOMETRIC MEASUREMENT INSTRUMENT, FINAL REPORT, SEPTEMBER 1963-NOVEMBER 1965 by H. P. Taylor and J. A. Campbell, November 1965, AFCRL 65-912, AD-629 583, Contract AF-19(628)-3239 (Unclassified).

Previous calculations show that due to the heavy adsorption of the atmospheric oxygen, the resultant radiation both in the wells and in the cores of the 60 gc/s spectral complex provides a radiometrically bright mantle surrounding the Earth. When viewed from space, this oxygen mantle could supply a uniform nonfluctuating signal for radiometric vertical sensing. This possibility of utilizing the thermal properties of the Earth's oxygen mantle as a reference for Earth vertical sensing from satellite vehicles provided the primary stimulus for the radiometric development program reported on herein. One of the primary problems in defining the performance of a local vertical sensor is that there is no good absolute reference that can be used to determine the sensor error. Thus, where the vertical stability of the satellite is not well enough known to

evaluate the perfo.mance of a vertical indicator, it is necessary to resort to a more indirect means. By the use of a relatively narrow antenna beam looking vertically downward, the temperature distribution of the oxygen mantle as a function of latitude on the Earth's surface can be determined.

1069. Falbel, G. and Astheimer, R. W., INFRARED HORIZON SENSOR TECHNIQUES FOR LUNAR AND PLANETARY APPROACHES, Progress in Astronautics and Aeronautics, Vol. 13, 1964, pp. 551-582.

Problem of determining attitude information with respect to various planets by means of their self-emitted IR radiation is considered; IR characteristics of Earth, moon, Mars, and Venus; description of conical scan, edge tracking, and radiometric balance type; horizon sensing systems and their applicability for these planets; and accuracy of systems is analyzed and compared as function of their design parameters, and physical characteristics of several planets.

1070. Flink, J. H., STAR IDENTIFICATION BY OPTICAL RADIATION ANALYSIS, IEEE Transactions on Aerospace Navigational Electronics (USA), Vol. ANE-10, No. 3, September 1963, pp. 212-221.

This paper is concerned with the problems of recognizing stars by means of their optical radiation characteristics, for use in the guidance and navigation of aerospace vehicles. We conclude that there are three easily measurable independent parameters in the radiation from individual stars which permit unique recognition of the brightest stars above the Earth's atmosphere. Accurate spectral data obtained from observations using three wide-bandwidth optical filters are given for the 71 brightest stars. The spectral parameters of a bright star are compared to previous observations to identify the unknown star. However, as a result of measurement inaccuracies the star may be incorrectly classified. Thus, the ave; age probability of misidentifying any of the brightest stars is calculated as a function of various measurement errors, assuming an "optimum" recognition proce.lure.

are involved may be accomplished by nuclear detection apparatus. Four separate techniques are outlined. Mossbauer and velocity-swept Mossbauer sensors, inverse square law variation, and atomic resonance methods are discussed. Calculations of performance capabilities and comparisons of relative merits are made for these methods. Some design criteria and description of required instrumentation also are presented.

1071. General Precision, Inc., Tarrytown, New York, STUDY OF MULTI-FUNCTION SENSORS FOR GUIDANCE SUBSYSTEMS, FINAL REPORT, 1 JULY 1962-30 JUNE 1963 by A. A. Miccioli, December 1963, RTD-TDR-63-4049, AD-425224, N64-13127, Avionics Laboratory, Wright-Patterson Air Force Base, Ohio, Contract AF-33(657)-9207 (Unclassified).

Experimental and analytical investigations of the extension of the GPL area correlation technique from terrain matching to simultaneous star field and beacon tracking in the context of a space rendezvous mission were conducted. It was inidcated that the extension was a feasible one. Simultaneous (dual-mode) star field and beacon tracking was successfully demonstrated in the laboratory.

1072. General Precision, Inc., Tarrytown, New York, STUDY OF MULTI-FUNCTION SENSORS FOR GUIDANCE SUBSYSTEMS SECOND QUARTERLY TECHNICAL NOTE, 1 OCTOBER-31 DECEMBER 1962 by A. Bloch, April 1963, N63-14754, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio, Contract AF-33(657)-9207 (Unclassified).

The purpose of the program detailed herein is the ultimate development of multifunction sensors for space-vehicle guidance and navigation. This second quarterly report contains detailed discussions of the work carried out during the reporting period. A section is devoted to the theory of Fresnel zone plates.

1073. Fontana, A.,
A PHOTOVOLTAIC SOLAR SENSOR FOR USE IN SPACECRAFT ORIENTATION CONTROL SYSTEMS, (M.S. Thesis) February 1966, NASA TN-D-3279, N66-16560.

A simple photovoltaic solar sensor has been designed, constructed, extensively ground tested in simulated space environments, and space tested during a suborbital flight. The sensor has the capability of solar capture from any initial orientation within its spherical field of view and the capability of accurate pointing toward the solar target without the introduction of error by earth-reflected solar radiation. The sensor has a repeatability of ±2.4 seconds of arc at a pointing error of one minute of arc. The sensitivity and linear range of the sensor are adjustable. State-of-the-art protection from space radiation degradation is provided. The sensor is conservatively estimated to have an earth-orbit lifetime of 10 years with no more than 10-percent degradation.

1074. Freeman, D. J.,
AUTOMATIC LATITUDE AND LONGITUDE SENSING TECHNIQUE FOR EARTH SATELLITES, Aerospace Engineering, Vol. 21, November 1962, pp. 48-53.

Not abstracted.

1075. Fuhs, A. E. and Kelly, J. A.,
ZERO ANGLE-OF-ATTACK SENSOR, AIAA Journal, Vol. 2, August 1964, pp. 1492-1493.

Not abstracted.

1076. General Electric Co., Missile and Space Division, Philadelphia, Pennsylvania,
VELOCITY AND POSITION SENSING BY MEANS OF RESONANCE DOPPLER TECHNIQUES by R. Zito, Jr., October 1963, AD-420 026 (Unclassified).

The problem of maneuvering and guiding spacecraft during the last stages of docking and mating are considered briefly in the light of the measurement of relative positions and velocities. Accurate determination of speed and separation between space vehicles when distances of 200 feet or less

1077. General Precision, Inc., Tarrytown, New York,
STUDY OF MULTI-FUNCTION SENSORS FOR GUIDANCE SUBSYSTEMS, THIRD QUARTERLY TECHNICAL NOTE, 1 JANUARY-MARCH 1963 by A. Bloch, May 1963, N63-16826, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio, Contract AF-33(657)-9207.

The purpose of the program is the ultimate development of multifunction sensors for space-vehicle guidance and navigation. This report contains detailed discussions of the work carried out during the reporting period. A section is devoted to the theory of overlapping Fresnel-zone plates.

1078. Goetz, R. A.,
INFRARED HORIZON SCANNERS, Arma Engineering, Vol. 4, No. 1, March 1961, pp. 6-13.

Included are problem areas and design techniques of passive device used for compensating space vehicle inertial system through establishment of Earth's horizon by detecting thermal discontinuity between Earth and space; features of sensing system of device which consists of infrared detector, collecting optics, and scanning mechanism.

1079. Greene, J.,
THE CELESTIAL TRACKER AS AN ASTRO COMPASS, IEEE Transactions on Aerospace Navigational Electronics (USA), Vol. ANE-10, No. 3, September 1963, pp. 221-235.

This paper describes a navigational system which accurately determines aircraft true heading and an altitude intercept from which position is determined. This is accomplished by automatically and continuously tracking the light from a celestial body with a stabilized telescope utilizing a photomultiplier tube as the sensor. The line-of-sight to the body is accurately measured with respect to the local vertical and used to correct computed pointing commands. The computed information is determined from aircraft position, celestial data, and time.

1080. Harmon, W. L., Shroyer, G. J., and Gilkey, K. J., OPTICAL TRACKERS IN SPACE, ISA Journal, Vol. 9, No. 11, November 1962, pp. 70-73.

In this paper is a discussion of optical trackers as accurate passive systems for spacecraft navigation systems. Optical trackers can use natural radiation from various celestial bodies to give attitude and position data to space navigators.

1081. Harrington, D. C., NOISE ERROR ANALYSIS OF OPTICAL STAR AND PLANET SCANNER, IEEE National Aerospace Electronics Conference-Proceedings, 1963, pp. 134-142.

Discussed in this paper is an investigation of fundamental and instrumental limitations to accuracy of scanning optical detectors for space-borne celestial navigation systems as affected by scan rate, target intensity, target photon noise, background radiation noise, and detector noise. To cover wide range of applications, scan periods of 10^{-2} to 10^{8} seconds must be considered, necessitating four distinct instrumentation arrangements, which are discussed.

1082. Holland, J. E., A NEW GENERATION SPACEBORNE GUIDANCE SENSOR STELATRAC, American Institute of Aeroanutics and Astronautics, Guidance and Control Conference, Cambridge, Massachusetts, 12-14 August 1963, Paper 63-349, A63-20670.

This paper is a description of a new means for stabilizing phase-lock receivers, called the injected reference technique, and of its incorporation into Space Technology Laboratories Tracking and Command (STELATRAC), a modular all solid-state X-band guidance sensor. The requirements for rendezvous and docking, and lunar landing sensors, are briefly summarized. Functional and performance flexibility of the sensor is indicated by its use as a docking radar, high altitude altimeter, and horizontal velocity meter, either separately or in combination. Reliability data on the feasibility model confirm a mean time between failures (MTBF) estimate of 4000 to 6000 hours. Packaging problems are examined,

and experimental data pertaining to system performance is included throughout the discussion. A means of achieving transmitter-receiver isolation is described in order to adapt STELATRAC to altimetry and velocity sensing. Electrical and physical characteristics and MTBF estimates of the sensors are included.

1083. Hughes Aircraft Co., Aerospace Group, Culver City, California, STUDY OF ADVANCED ANTENNA TECHNIQUES FOR AEROSPACE VEHICLE DOPPLER VELOCITY SENSORS, QUARTERLY ENGINEERING REPORT NO. 3 by T. S. Fong, November 1963, P-63-74, AD-422967, N64-13128, Contract AF-33(657)-10672 (Unclassified).

The investigation is concerned with a flush-mounted antenna for an active Doppler velocity sensor for reentry-glide navigation on space vehicles. This antenna is required to generate four symmetrically oriented beams about its normal with 20 to 30 decibels of isolation (for pulsed operation) between the signals which are transmitted and received along each beam. In addition, the antenna beam direction must not be affected by variation in the attitude of the vehicle. A two-dimensional array of slots in square waveguide with four isolated feed ports was devised to meet this requirement. The array consists of a number of square waveguide branch lines which are fed by two square waveguide feed lines. Port isolation is obtained by utilizing the polarization isolation that exists between the TE_{10} and TE_{01} modes in the square waveguide.

1084. Irish, L. A., GUIDANCE EQUATIONS FOR AUTOMATIC DOCKING, DERIVATION OF PITCH AND YAW TRANSLATION CONTROL EQUATIONS, Advances in the Astronautical Sciences, Vol. 16, Pt. 1, Space Rendezvous, Rescue, and Recovery, North Hollywood, California, Western Periodicals Co., 1963, pp. 3-15, A63-24745 (U.S. Air Force and American Astronautical Society, Space Rendezvous, Rescue, and Recovery, Symposium, Edwards Air Force Base, California, 10-12 September 1963).

This article is a presentation of basic equations for the automatic control of docking in space. Sensor configurations that might satisfy requirements for determining the positions and attitudes of interceptor and target vehicles in an arbitrary

coordinate system are outlined; these configurations include the use of a coded optical beacon, bilateral tracking, and a three-dimensional optical array. Considered are pitch and yaw attitude control, roll attitude control, and pitch and yaw translation control.

1085. Kamen, S. K. and Tanenbaum, M. S.,
SATELLITE-BASED RADAR SEEKER DESIGN, National Convention on Military Electronics, 7th, Washington, D.C., 9-11 September 1963, Proceedings, New York, Institute of Electrical and Electronics Engineers, 1963, pp. 108-111, Contract AF-29(601)-5240, A64-22497.

This paper is a discussion of the requirements of a satellite-based seeker operating with a noncooperative object. This includes such missions as the rescue and recovery of friendly craft whose means of cooperation have failed, as well as rendezvous with unknown craft for inspection and possible destruction. The potentially applicable sensors are reviewed, and the reasons for the choice of a satellite-based radar for certain missions are presented. A design procedure is described, and the results are presented for typical values of initial position uncertainty of the object, closing rate, range, time to achieve detection, transmitter power, antenna aperture, and frequency. As an example, it is shown that a radar can be designed to provide terminal guidance for ranges up to 400 nautical miles with an initial position uncertainty of five miles with present techniques.

1086. Kamm, L. J.,
MAGNETORQUER; A SATELLITE ORIENTATION DEVICE, ARS Journal, Vol. 31, June 1961, pp. 813-815.

Not abstracted.

1087. Kamm, L. J.,
VERTISTAT; IMPROVED SATELLITE ORIENTATION DEVICE, ARS Journal, Vol. 32, June 1962, pp. 911-913.

Not abstracted.

1088. Karrenberg, H. K. and Roberson, R. E., CELESTIAL RATE SENSING, ARS Journal, Vol. 31, March 1961, pp. 440-441.

Not abstracted.

1089. Kovit, B., IR HORIZON SENSOR GUIDES PLANETARY ORBITING, Space/Aeronautics, Vol. 35, February 1961, pp. 131-133.

Not abstracted.

1090. Kresa, K. and Bohne, C. R., ATTITUDE SENSING DURING EXTRA-ATMOSPHERIC AND RE-ENTRY FLIGHT, American Institute of Aeronautics and Astronautics, Space Flight Testing Conference, Cocoa Beach, Florida, 18-20 March 1963, Paper 63109, A63-17228.

This article is a presentation of a technique for determining the inertial attitude of a spinning vehicle during both extra-atmospheric and reentry flight with an anticipated accuracy of three degrees and a weight of approximately 2.5 pounds. In its simplest form, the technique incorporates three magnetometers and a horizon sensor which determine the instantaneous orientation with respect to the Earth during the extra-atmospheric portion of the trajectory. Immediately prior to reentry, a two-axis free gyroscope, aligned with the spin axis of the vehicle, is uncaged. The inertial orientation of the vehicle is then determined from the magnetometer and horizon sensor system. The motion of the vehicle with respect to the gyro-spin axis is determined from a measurement of the gimbal motions, thereby determining the vehicle orientation throughout the reentry event. The results of component and system testing during spinning and coning motion are presented. An error analysis for a flight system is included.

1091. Laverty, N. P., THE COMPARATIVE PERFORMANCE OF ELECTRON TUBE PHOTODETECTORS IN TERRESTRIAL AND SPACE NAVIGATION SYSTEMS, IEEE Transactions on Aerospace Navigational Electronics (USA), Vol. ANE-10, No. 3, September 1963, pp. 194-205.

Celestial tracking systems employed in the navigation of military vehicles in the atmosphere of the earth have the

capability of tracking a large number of stars in the daytime. In daytime tracking, the quantum efficiency of the detector, as well as additional sensitivity gain through electronic charge storage, is of primary importance. Theoretical formulae for the signal-to-noise ratios of four detectors are presented: the photoelectric photomultiplier, image dissector, vidicon and the image orthicon. The photomultiplier and image dissector require the use of very slow scanning velocities, narrow-detection bandwidths, and the resultant time required for star acquisition is in the order of minutes. The image orthicon, due to target saturation, is restricted to the observation of only bright stars. The vidicon, with sensitivity gain through electronic charge storage, is used with rapid scanning velocities. and star acquisition is accomplished in less than one second of time. In interplanetary or nighttime navigation, with a low level of background radiation, the salient detector characteristics are sensitivity, gain through either storage of photomultiplication, and dark current. The image dissector rates first among the detectors considered, followed by the photomultiplier, image orthicon, and the vidicon. Field test data are presented in this work in substantiation of the analysis of the several detector types.

1092. Matthews, M. A. V.,
INERTIAL SYSTEMS IN SPACE VEHICLES, Journal of British Institution of Radio Engineers, Vol. 22, No. 3, September 1961, pp. 231-239.

This paper is a discussion of the use of inertial elements in space vehicles for attitude control and navigation. Some limitations of inertial systems in this environment are described and it is shown that inertia alone is not adequate for most space applications. However, the use of inertia to bridge the gaps between information from other sources can simplify the requirements for other sensors in the satellite, and also on the ground tracking equipment. This is illustrated by some examples and by discussion of the characteristics of inertial components suitable for a space vehicle.

1093. Matthews, R. B. and Henderson, J. G., VELOCITY MEASUREMENTS WITH MOSSBAUER EFFECT, IEEE National Space Electronics Symposium, PTGSET Record, Paper 5.5, October 1963, 9 pp.

Velocity measurement system, in which accuracy is independent of variations in transmitting environment, appears feasible by applying Mossbauer effect of nuclear "resonance" at gamma frequencies; Mossbauer effect offers possibility of quantitatively measuring Doppler shifts to one part in 10^{12}; Mossbauer effect physics are reviewed and characteristics of Mossbauer materials summarized; typical demonstration experiment is described with attention to velocity sensor and operational boundaries; and applications include missile's initial trajectory, altitude for space vehicles attempting soft landings, and closure rates between vehicle and space station or another vehicle.

1094. McCanless, F. V., A SYSTEMS APPROACH TO STARTRACKERS, IEEE Transactions on Aerospace Navigational Electronics (USA), Vol. ANE-10, No. 3, September 1963, pp. 182-193.

A signal processing analysis of startrackers for navigation and guidance was conducted as a part of the Startracker Aerospace Reference Study. The signal processing analysis is based on the similarity between communication system theory and the several types of startrackers. The navigation system and startracker parameters are the trade-off items that permit operation within the bounds set by the star field and transmission path. A tracker parameter analysis is an aid in formulating criteria for selecting a tracker and judging performance. This paper is primarily concerned with the internal parameters of startracker design; and specifically, what methods are available to the designer to meet navigation, guidance, and star ephemeris requirements. Equations describing the modulation process are developed and compared to communication practices. To aid in the comparison of the various types of trackers, a representative set of parameters has been developed. The comparison is done on a graphical basis where the primary trade-offs are effective optical area, information bandwidth and angular accuracy. The expected range of background radiance, star distribution and effect irradiance are described in summary form. Sources of additional information are listed in a bibliography.

1095. McGraw-Hill Inc., New York, New York,
SPACE OPTICS A REVIEW OF FOREIGN TECHNOLOGY DURING 1964-1965 by R. S. Estey, June 1965, MHR-65-11-A, AD-471 385L, Contract AF-33(657)-13378 (Unclassified).

This document has four sections covering compilation of available literature fragments, application of space optical techniques to astronautics, reentry and recovery of soviet manned space vehicles, and a review of voskhod material and evaluation of the voskhod system.

1096. Merlen, M. and Grossman, D.,
INTERROGATOR CIRCUIT CAN TELL GOOD DATA FROM BAD, Electronics, Vol. 37, 13 July 1964, pp. 58-59.

Not abstracted.

1097. Naqvi, A. M. and Levy, R. J.,
SOME ASTRONOMICAL AND GEOPHYSICAL CONSIDERATIONS FOR SPACE NAVIGATION, IEEE Transactions on Aerospace and Navigational Electronics, Vol. ANE-10, No. 3, September 1963, pp. 154-170.

Position and velocity of the space vehicle is determined by using optical measuring equipment contained in the vehicle; techniques are correlated with measurements made from Earth; information on stellar position, magnitudes, spectra and frequency distribution is presented; and problems arising from presence of Earth's atmosphere in observing terrestrial occultations are considered in view of such atmospheric characteristics as cloudiness, absorption, scattering, and emission of radiation.

1098. National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama,
THE INFLUENCE OF CONTROL SENSORS ON THE STABILITY OF SPACE VEHICLES, by M. H. Rheinfurth, 22 August 1961, MTP-Aero-61-65 (Unclassified).

This report discusses the stability of sensors, stability of the-angle-of-attack recording devices, stability of the linear control systems, stability of accelerometers, stability of space vehicles, stability of gyroscopes, stability and design

of altitude control systems, and stability and control stability and control of the Saturn vehicle.

1099. National Aeronautics and Space Administration, STUDY OF A PROPOSED INFRARED HORIZON SCANNER FOR USE IN SPACE-ORIENTATION CONTROL SYSTEMS by N. M. Hatcher and E. F. Germann, Jr., January 1962, NASA TN D-1005 (Unclassified).

The design features of a proposed compact attitude and altitude sensor for space vehicles are discussed. The sensor optically scans the infrared radiation discontinuity between space and the horizon of a planetary body to produce an attitude and altitude signal. The sensor should be capable of operating throughout a wide altitude range. Altitude range, capture capability, lifetime, and an experimental sensor are discussed. The sensitivity of the sensor and the radiation discontinuity which the sensor detects between space and the horizon of the planetary body are analyzed, and theoretical curves showing the variation of this detected discontinuity with distance from the Earth, Mars, Venus, and the moon are presented.

1100. National Aeronautics and Space Administration, STUDY OF A SOLAR SENSOR FOR USE IN SPACE-VEHICLE ORIENTATION CONTROL SYSTEMS by P. R. Spencer, June 1961, NASA TN D-885 (Unclassified).

A solar sensor is proposed to meet the existing need for orienting space vehicles toward the sun. Consideration has been given to such requirements as reliability, capture capability, sensitivity, and power consumption. The effects of varying certain design parameters are shown and improvements are suggested. The effects of a space environment are discussed. Results obtained from an experimental model of a solar sensor are presented.

1101. National Aeronautics and Space Administration, STUDY OF EFFECT OF ERRORS IN MEASUREMENT OF VELOCITY AND FLIGHT-PATH ANGLE ON GUIDANCE OF SPACE VEHICLE APPROACHING EARTH by J. A. White, NASA, October 1961, TN D-957.

Included is a study made to determine effect of errors in measuring velocity and flight path angle, in applying

corrective thrust, and in initial predicted perigee altitude upon guidance of vehicle to desired perigee altitude; method scheduling observation points along trajectory was to make observation (and to apply correction if needed) each time true anomaly increased given amount.

1102. Newcomb, A. L., Jr., Groom, N. J., and Hatcher, N. M., A NOVEL MOON AND PLANET SEEKING ATTITUDE SENSOR FOR USE IN SPACECRAFT ORIENTATION AND CONTROL, Institute of Electrical and Electronics Engineers, International Convention, New York, New York, 22-26 March 1965, IEEE International Convention Record, Vol. 13, Pt. 4, 1965, pp. 48-54, (A65-22149).

Included is an attitude sensing horizon scanning device that detects the thermal radiation discontinuity at opposite ends of a planetary body. An experimental model has been constructed and used for testing purposes. Results of tests with the experimental model indicate that the scanner would have an instrument-associated error of less than one degree, an SNR that would allow it to operate at altitudes of about a million miles from the Earth, a power consumption rate of about 3.5 watts, the ability to eliminate false signals from the sun, and a wide-angle capture capability.

1103. Norton, R. H. and Wildey, R. L., FUNDAMENTAL LIMITATIONS TO OPTICAL DOPPLER MEASUREMENTS FOR SPACE NAVIGATION, IRE Proceedings Vol. 49, No. 11, November 1961, pp. 1655-1659.

From physical theory of line broadening and shifting mechanisms in stellar atmospheres, it is concluded that intrinsic variability of plus or minus 200 fps may be expected in measurement of observer's Doppler velocity. An examination of current state-of-art in measuring equipment suggests that it does not set limits on accuracy.

1104. Novik, B. F., THE USE OF LONGITUDINAL PHOTOCELLS IN POINTING, Geodesy and Aerophotography, No. 1, 1965, pp. 54-56, A66-14398 (Geodeziia i Aerofotos'emka, No. 1, 1965, pp. 123-128).

Not abstracted.

1105. Quasius, G.,
A TOPOLOGICAL APPROACH TO THE ANALYSIS OF STARTRACKING SYSTEMS, IEEE Transactions on Aerospace Navigational Electronics, (USA), Vol. ANE-10, No. 3, September 1963, pp. 206-212.

The systems engineer, in formulating and analyzing star-tracking systems, is often confronted with conversion of lengthy coordinate tranformation matrices into meaningful physical data. The matrices associated with vector analysis and the equations of spherical trigonometry used in celestial and space applications often defy orderly and concise interpretation. One becomes lost in a maze of sines, cosines, and error vectors. The topological method of performing orthogonal coordinate transformations graphically illustrates the conversions and projections being attempted and serves as a map to orient our thinking. This paper discusses coordinate transformation of startracking systems in terms of the topological and signal flow chart. The topological or signal flow diagram is briefly explained before being applied to typical startracking problems. Star identification in space and terrestrial navigation were chosen as representative problems to illustrate the usefulness of the topological analysis approach.

1106. Rodden, J. J. and Montague, L. D.,
DESIGN OF AN ATTITUDE CONTROL SYSTEM WITH MAGNETOMETER SENSORS, AIAA Journal, Vol. 1, 4 June 1963, pp. 1422-1444.

Not abstracted.

1107. Sandeman, E. K.,
FM STAR-LOCK SYSTEM USING MASK WITH LINEAR SECTORS, IRE Transactions on Aerospace and Navigational Electronics, Vol. ANE-9, No. 1, March 1962, pp. 24-47.

Included is a star-lock system in which rotating element in optical system causes image of star field to nutate over surface of mask divided into opaque and transparent sectors; when lock star is on axis of entry optical system, unvarying frequency is produced in output of photocell behind mask; with misalignment of star image from axis of entrance optical system, output of photocell is frequency modulated; resulting FM wave is processed to provide misalignment signals along

two axes; and pertinent parameters for systems using mask with linear or spiral sectors.

1108. Sanders, J. C., Gettelman, C. C., Warshawsky, I., and Hiller, K. W.,
INSTRUMENTATION FOR MEASUREMENT AND CONTROL, 4-5 June 1964, pp. 153-181 (NASA-SP-54).

Principal elements of closed-loop control system, namely; sensors, information-processing chain, actuators, and final elements, are considered; specific spacecraft sensors, such as magnetometers, charged particle detectors, infrared radiometers, are described as are sensors for force, torque, pressure, flow and temperature employed in ground-based measurements; and steps in information processing, data assembly, transmission, analysis, and presentation are illustrated by example of nuclear-rocket test, such as one used to launch Mariner.

1109. Stanfield, W. G.,
TWIN GYRO ATTITUDE CONTROL SYSTEM DESIGNED FOR DISTURBANCE INSTRUMENTATION OF SPACE VEHICLE, SAE Paper 865C for meeting 27-30 April 1964, 6 pp.

Included is a system developed by Ling-Temco-Vought, Inc. for Electric Propulsion Space Test System project (WS-661A); principal characteristics of concept and key features; concept, intended as actuation device for attitude control, incorporates features making it possible to be used as measuring device to measure torques imparted to space vehicle; installation and construction considerations; and advantages include availability of direct, accurate readout of applied torque, use of off-the-shelf components, good dynamic response characteristics, redundancy, low power requirements, and low weight for angular momentum capacity.

1110. Searcy, J. B.,
STARTRACKING, IRE - Northeast Electronics Research and Engineers Meeting, NEREM Record, Vol. 4, 1962, pp. 168-169.

Optical trackers may be divided into two categories: (1) includes trackers in which reference measurement line is identified uniquely with each sensitive axis, and remains

fixed in tracker coordinates along its associated sensitive axis; and (2) includes those trackers in which single reference measurement line is time shared between two sensitive axes; thus it must move in tracker coordinates; and factors which must be taken into account to arrive at optimum tracker for given application.

1111. Speen, G. B.,
GAS SUPPORTED DUAL ELEMENT GYRO FOR SPACE USE,
Fourth Joint Automatic Control Conference (New York, American Institute of Chemical Engineers, 1963) pp. 420-424.

This article describes a two-axis, nontorquable, free inertial reference for space applications. It offers extremely long life, high reliability, small size, low weight, tolerance to environmental extremes, very low drift, and requires minimum power. It is a member of the class known as "bootstrap" gyros because its theoretical drift rate can be reduced without limit as the performance of the platform on which it is mounted is improved. This combination of features makes it ideally suitable for space use. The gyro derives its excellent theoretical accuracy from a combination of features which include: (1) the application of gas lubricated bearings to eliminate starting friction and (2) the rotation of the rotor support system to cancel disturbing torques. Design concepts and operational properties are discussed to demonstrate the applicability of the gyro to space requirements.

1112. Stevens, F.,
STARTRACKERS FOR INTERPLANETARY VEHICLES,
Society of Automotive Engineers, Vol. 69, No. 1, January 1961, pp. 84-85 (From book titled "Vistas in Astronautics - 1960").

Key to optical navigation is precision star sensor and tracker which should have the following characteristics: adequate acquisition field, small tracking field, high resolution after acquisition, no loss of central sensitivity, and practical size, power drain, and reliability; design of system and how requirements are met; and performance attainable.

1113. Viglione, S. S. and Wolf, H. F.,
STAR FIELD RECOGNITION FOR SPACE VEHICLE ORIENTATION, IRE East Coast Conference on Aerospace and Navigational Electronics - Technical Paper 1.2.5 for meeting 22-24 October 1962, 4 pp.

A technique is described which allows determination of vehicle orientation independently of knowledge of previous attitude and despite large deviations from planned trajectory; coarse measurement of orientation is obtained by searching for an identifying well-known star patterns on celestial sphere; specific star is then selected for precision measurement whose geometric relation to pattern is known; system employs mosaic retina of photovoltaic cells in conjunction with majority logic network; and hardware requirements for feasibility model are defined.

1114. Vyce, J. R.,
INTRODUCTION TO GYRO OPTICAL PICKOFFS, Journal of Spacecraft and Rockets, Vol. 2, No. 5, September-October 1965, pp. 681-688.

Optical pickoff provides a satisfactory solution to the problem of sensing attitude of aerostatic, electronsatic, and cryomagnetic field-suspended spherical-rotor gyros that are invariably operated in space-fixed mode; servos in gimballed gyros are controlled by optical pickoff to maintain pickoff aligned with rotor, usually parallel to rotor spin axis; operating principles of two types of pickoffs, autocollimator and autoreflector, are explained and their performance evaluated; autocollimator accuracy falls in one-tenth to one arc-second region; autoreflector accuracy is about one microinch; and strapdown readout system is capable of measuring with 10 to 100 arc-second accuracy.

1115. Wallace, R.,
RADAR SYSTEM DESIGN FOR SPACECRAFT TERMINAL CONTROL, IEEE Transactions on Aerospace, Vol. AS-2, April 1964, pp. 139-144, A64-18092 (International Conference and Exhibit on Aerospace Electro-Technology, Phoenix, Arizona, 20-23 April 1964).

Included is a discussion of several radar design considerations for use in the terminal control of manned and

unmanned space vehicles of the maneuverable type, in particular, the specific areas of radar development resulting from recent work in developing a terminal control system. The radar system discussed uses a transponder on board the vehicle. The transponder receives and transmits pulse code modulated (PCM) commands and flight data in addition to reference pulses for angle and range tracking. The technical areas discussed are reliability of self-acquisition, PCM data transmission, semidigital ranging, and the accuracy of computed radar data.

1116. Wark, D. Q., Alishouse, J., and Yamamoto, G., VARIATION OF INFRARED SPECTRAL RADIANCE NEAR LIMB OF EARTH, Applied Optics, Vol. 3, No. 2, February 1964, pp. 221-228.

Infrared radiance near limb of Earth was calculated in narrow spectral intervals for four atmospheric models representing wide range of meteorological conditions; two hypotentical filters are convoluted with spectral radiance to show effective radiance across limb, as it might be viewed by horizon sensor; and results indicate that 15-micro carbon dioxide band and rotational vapor band are best suited for horizon sensing and that neither is decisively superior on basis of radiance.

1117. Wheeler, M. S. and Hacker, P. S., INTERFEROMETER IS DESIGNED FOR GEMINI RADAR, Electronics, Vol. 35, 30 November 1962, p. 106.

Not abstracted.

1118. White, C. E., SPACECRAFT SENSORS, Space/Aeronautics, Vol. 38, December 1962, pp. 70-72.

Not abstracted.

1119. Zito, R., Jr.,
VELOCITY SENSING FOR SPACECRAFT DOCKING, Space/Aeronautics, Vol. 40, December 1963, pp. 90-93.

Not abstracted.

1120. Zuckerbraun, J. S.,
HIGH-RELIABILITY SCANNERS FOR STELLAR NAVIGATION, Electronics, Vol. 35, No. 19, 11 May 1962, pp. 82-85.

Included are startracking devices providing high reliability and accuracy for space experiments. They include vibrating-reed scanner, which will be used in six startrackers deployed around NASA's Orbiting Astronomical Observatory vehicle as part of its coarse guidance system (30 seconds of arc), and tuning-fork scanner planned for fine guidance system (0.1 second of arc) for Goddard ultraviolet experiment.

1121. Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio,
BASIC APPLIED RESEARCH IN FLUID POWER CONTROL, FIFTH AND SIXTH PROGRESS REPORTS, February 1964, RTD-TDR-63-4252 (Unclassified).

This report presents technical results and describes progress in several phases of continuing applied research and development related to the design and development of high-performance fluid control devices for advanced aerospace systems. Continued emphasis is placed on pneumatic components and systems which are capable of performing over wide ranges of temperature and in the presence of intense radiation.

This report describes current work in the Engineering Projects Laboratory dealing with a new pneumatic pulse actuation servo system, a gas-operated accelerometer, the dispersion of transients in fluid transmission lines, compressible dampers, negative-stiffness flapper valves, and gas-lubricated bearings.

1122. Aerospace Corporation, Los Angeles, California,
ANALYTICAL INVESTIGATION OF NITROGEN JET REACTION CONTROL SYSTEMS by H. Greer, November 1964, TDR-469(5560-30)-1, SSD TDR-64-242, AD-453 193, Contract AF-04(695)-469 (Unclassified).

The experimental results of a nitrogen jet reaction control system are analyzed and correlations between theoretical and measured parameters are established. It is shown that accurate analytical predictions of impulse bit size, gas consumption, and effective specific impulse can be accomplished. Generalized performance relationships are presented over a range of thrust chamber geometry and pressure ratio as a function of command pulse width.

1123. Aerospace Corporation, El Segundo, California, LOW THRUST REACTION JET PERFORMANCE, TECHNICAL DOCUMENTARY REPORT by H. Greer and D. J. Griep, August 1965, TDR-469(5230-33)-2, SSD TR-65-122, AD-470 960, Contract AF-04(695)469 (Unclassified).

The propulsive performance characteristics of several cold-gas reaction jet systems that might typically be used for attitude control of small spacecraft are analyzed and compared with the results of laboratory experiments with nitrogen, ammonia, freon-12, and freon-14. The transient processes dominating the short-pulse or limit-cycle mode of thruster operation in space are formulated using a gas dynamical approach. The results correlate well with the experimental data. The unusual features of the experimental apparatus, procedures, and data processing techniques required to obtain accurate test results for a low-thrust dynamic mode of operation are described. Impulse bit size, gas consumption, and effective specific impulse are parameterized in terms of thruster geometry, gas properties and command pulse width to provide a systematic basis for system design optimization.

1124. Aerospace Corporation, Los Angeles, California, SYSTEM CONSIDERATIONS OF ELECTRIC PROPULSION FOR NEAR-EARTH MISSIONS by M. J. Russi and W. H. Lien, 1963, AD-406 599 (Unclassified).

Although it is generally accepted that electric propulsion will be extremely useful for deep space missions, its usefulness for near-earth missions is not as apparent. Three of the near earth uses suggested for electric propulsion are examined and compared with other means of accomplishing the same task. The results of this limited investigation indicate that: (1) The performance and cost advantages of electric propulsion over relatively simple chemical propulsion do not appear to be sufficient to warrant its use for delivering a nuclear powerplant to a 24-hour equatorial orbit. (2) Electric propulsion does not appear to be competitive weight-wise-with other propulsive and nonpropulsive methods for providing satellite limit cycle attitude control since the energy requirements for this function are quite small. (3) If the need for low and altitude orbit sustaining can be established, the energy requirements over a long

period of time are sufficiently high so that nuclear electric propulsion offers substantial savings in system weight and cost compared to chemical propulsion. Based on the above results, it is concluded that electric propulsion will be useful only for those near-earth missions and functions which can take advantage of its high energy-high impulse characteristics. Atleast two of the above applications suggested for electric propulsion do not meet this requirement.

1125. Air Force Systems Command, Foreign Technical Division, Wright-Patterson Air Force Base, Ohio, ENGINES FOR INTERSTELLAR SHIPS by R. G. Pereliman, September 1963, FTD TT-63-92, AD-420 610 (Unclassified).

CONTENTS

1126. Air Force Systems Command, Foreign Technical Division, Wright-Patterson Air Force Base, Ohio, THE PROBLEM OF ELECTRON JET ENGINES AND THE DIRECT CONVERSION OF HEAT ENERGY INTO ELECTRIC (FROM DATA IN THE FOREIGN PRESS) by A. Ye. Kaplyanskiy, April 1963, FTD TT-63-298-1-2-4, AD-415 668 (Translated from Elektrichestvo, No. 11, 1961, pp. 7-13) (Unclassified).

The problem of electron jet engines and the direct conversion of heat energy into electric energy are discussed.

1127. Air Force Systems Command, Foreign Technology Division, Wright-Patterson Air Force Base, Ohio,
THE TOMORROW OF AVIATION (SELECTED ARTICLES, September 1965, FTD-TT-65-745, TT 65-64051, AD-621 796 (Unclassified).

Not abstracted.

1128. Airesearch Manufacturing Co., Los Angeles, California,
ATMOSPHERIC CONTROL SYSTEMS FOR SPACE VEHICLES by J. Rousseau, March 1963, ASD-TDR-62-527, X63-12783, Contract AF-33(616)-8323 (Unclassified).

Not abstracted.

1129. American Radiator and Standard Sanitary Corporation, Mountain View, California,
DESIGN AND DEVELOPMENT OF A VAPORJET ATTITUDE-CONTROL SYSTEM FOR SPACE VEHICLES by R. S. Miksch, December 1961, ASD-TR-61-471, AD-272 694, U. S. Air Force Systems Command, Aeronautical Systems Division, Contract AF-33(616)-7044 (Unclassified).

This report summarizes a program of research and development of a lightweight, long-lived, jet-thrust-reaction, attitude-control system of high reliability for space vehicle application. In this system, termed "Vaporjet," the desired characteristics are obtained through low-pressure storage of propellant in its liquid state, with conversion at saturation pressure to vapor of high specific impulse.

1130. Anderson, J. S.
FLUID POWER, Space/Aeronautics, Vol. 44, No. 2, 1965-1966, pp. 127-130.

Not abstracted.

1131. Arnold Engineering Development Center, Arnold Air Force Station, Tennessee,
INTERACTIONS PRODUCED BY SONIC LATERAL JETS LOCATED ON SURFACES IN A SUPERSONIC STREAM by W. T. Strike, C. J. Schueler, and J. S. Deitering, April 1963, TDR-63-22, AD-401 911, Contract AF-33(600)-1000 (Unclassified).

This report discusses interaction produced by sonic lateral jets located on surfaces in a supersonic stream.

1132. Auburn University, Auburn, Alabama,
AUBURN RESEARCH FOUNDATION STUDY OF SPACE VEHICLE ENGINE POSITION CONTROL SYSTEMS, FOURTH TECHNICAL REPORT, 16 MAY 1962 - 1 FEBRUARY 1963 by D. W. Russell, 14 February 1963, NASA CR-51752, X63-16075, Contract NAS8-2484 (Unclassified).

Not abstracted.

1133. Auburn University, Auburn, Alabama,
STUDY OF SPACE VEHICLE ENGINE POSITION CONTROL SYSTEMS, THIRD TECHNICAL REPORT, 16 FEBRUARY 1962 - 15 MAY 1962 by D. W. Russell, 1 June 1962, NASA CR-50139, X63-15324, Contract NAS8-2484 (Unclassified).

Not abstracted.

1134. Author Unknown,
ADVANCED SYNCOM FIRES FOR HOME TO STAY STOPPED, Machine Design, Vol. 35, No. 8, 23 May 1963.

Not abstracted.

1135. Author Unknown,
HYDRAULIC COMPONENTS, Space/Aeronautics, Vol. 40, No. 2, 1963-1964, pp. 173-176.

Not abstracted.

1136. Author Unknown,
MOTOR AND POTENTIOMETER INTEGRATED ON COMMON SHAFT IN SPACE PROBE CONTROL UNIT, Electromechanical Components and Systems Design, Vol. 6, No. 10, October 1962, pp. 38-41.

A compact design package is described incorporating two infinite resolution components, viz a conductive plastic potentiometer feedback device and miniature slotless dc torque motor, as a vane actuating member of a mid-course guidance system on Ranger lunar and Mariner space vehicles.

1137. Author Unknown,
NOVEL TORQUE MOTOR DEFLECTS-RANGER'S JET VANES, Space/Aeronautics, Vol. 38, October 1962, p. 155.

Not abstracted.

1138. Author Unknown,
PNEUMATIC CONTROLS WILL STEER GEMINI-LANDING PARAGLIDER, Machine Design, Vol. 35, 18 July 1963, p. 14.

Not abstracted.

1139. Author Unknown,
PULSE-JET DESCENDANT STRAIGHTENS OUT SPACECRAFT, Machine Design, Vol. 34, 27 September 1962, p. 12.

Not abstracted.

1140. Author Unknown,
ROCKET EXPLODES CAPS TO CORRECT SPACECRAFT ATTITUDE, Machine Design, Vol. 34, 20 December 1962, p. 8.

Not abstracted.

1141. Author Unknown,
SUN-PRESSURE VANES STABILIZE SPACECRAFT, Machine Design, Vol. 37, 18 March 1965, pp. 22-23.

Not abstracted.

1142. Author Unknown,
TOROIDAL-WOUND DC TORQUE MOTOR STEERED MARINER, Machine Design, Vol. 35, 14 February 1963, p. 140.

Not abstracted.

1143. Author Unknown,
TWO MINIATURE ROCKETS FOR SPACECRAFT CONTROL, Chemical Engineering, Vol. 71, 7 December 1964, p. 84.

Not abstracted.

1144. Axelband, E. I.,
TORQUE COUPLED BANG-BANG ATTITUDE CONTROL, North Hollywood, California, Western Periodicals Co., 1964, pp. 1.1.6-1 to 1.1.6-10, A65-14930 (Annual East Coast Conference on Aerospace and Navigational Electronics, 11th, Baltimore, Maryland, 21-23 October 1964, Technical Papers, A65-14925).

Discussion of the properties of gas-jet torque-coupled attitude control in the design context of a coast-phase attitude control system for a nonatmospheric planetary landing space vehicle is included. The relative merits of coupled versus uncoupled gas-jet torquing are discussed. It is concluded that the use of coupled torquing introduces an unwanted dynamic interaction which can be avoided by the use of a timer in conjunction with the celestial reference acquisition logic. On the other hand, to achieve torque coupling, either two additional gas jets must be introduced or the available moment arm must be halved. In the first case, the asymptotic-mode gas consumption increases by 48%, and in the second, it is doubled for the nonasymptotic mode portions of the flight and increases by 196% for the asymptotic mode.

1145. Axelband, E. I.,
TORQUE COUPLED BANG-BANG ATTITUDE CONTROL, IEEE Transactions on Aerospace and Navigational Electronics, Vol. ANE-12, No. 2, June 1965, pp. 129-133.

Properties of gas jet torque coupled attitude control in design context of coast phase attitude control systems for nonatmospheric planetary landing space vehicles are discussed.

1146. Bailey, R. F.
PULSE OPERATED BIPROPELLANT REACTION CONTROL VALVES, Society of Automotive Engineers, 1965, pp. 89-94, A66-10668 (Aerospace Vehicle Flight Control Conference, Los Angeles, California, 13-15 July 1965, Proceedings, A66-10661).

This article discusses design considerations for pulse-operated bipropellant control valves. Bipropellant reaction control systems require unique propellant control valves. The response time of attitude control rockets for space vehicles is a function of the valve response. The minimum obtainable impulse bit is significantly influenced by the propellant valve characteristics. Four essential design parameters are considered as follows: reliability, performance, material compatibility, and weight. Reliability is obtained by simplicity of design. The primary performance requirements are fast response, zero propellant leakage, simultaneous operation of fuel and oxidizer metering, and contamination tolerance. Valve weight is minimized through use of a torque motor. Suitable materials are carefully evaluated for compatibility with the propellants, while maintaining a structurally sound unit.

1147. Bell Aerosystems Co., Buffalo, New York,
ANALYSIS OF AN OPTIMUM THRUST MODULATED PROPULSION SYSTEM FOR USE IN A SPACE MANEUVERING VEHICLE, VOLUME I - PROPULSION SYSTEM ANALYSIS (U), October 1964, RPL-TDR-64-120, BAC-8173-902007, Vol. 1, Contract AF-04(611)-8183 (Confidential).

Not abstracted.

1148. Bell Aerosystems Co., Buffalo, New York,
ANALYSIS OF AN OPTIMUM THRUST MODULATED PROPULSION SYSTEM FOR USE IN A SPACE MANEUVERING VEHICLE, VOLUME II, MISSION ANALYSIS, FINAL REPORT PART 1, FEBRUARY-JUNE 1964 (U) by J. Germano, W. Pearson, D. Sweitzer, J. Markand, and R. Austin, October 1964, RPL-TDR-64-120, BAC-8173-902007, Vol. 2, AD-354 437, Contract AF-04(611)-8183 (Confidential).

Not abstracted.

1149. Bell Aerosystems Co., Buffalo, New York,
ANALYSIS OF AN OPTIMUM THRUST MODULATED PROPULSION SYSTEM FOR USE IN A SPACE MANEUVERING VEHICLE, VOLUME III - APPENDICES (U), June 1964, RPL-TDR-64-120, BAC-8173-902007, Vol. 3, Contract AF-(611)-8183 (Confidential).

This document includes Appendices I through IV: Method of Analysis, Propulsion System Component Studies, Vehicle Performance Tradeoffs, and Advanced Gaseous F_2/H_2 Attitude Control System.

1150. Bell Aerosystems Co., Buffalo, New York,
HEAT TRANSFER DESIGN ANALYSIS DYNASOAR ATTITUDE JET ASSEMBLIES (U) by R. J. Harms, December 1962, BAC-8233-937001, AD-348 316 (Confidential).

Not abstracted.

1151. Bell Aerosystems Co., Buffalo, New York,
MANEUVERING SATELLITE PROPULSION SYSTEM DEMONSTRATION - PART 2, FINAL REPORT, MAY 1962 - JUNE 1964 (U), July 1964, RPL-TDR-64-121, BAC-8173-902009, AD-354 376, Contract AF-04(611)-8183 (Confidential).

Not abstracted.

1152. Bell Aerosystems Co., Buffalo, New York,
REACTION CONTROL SYSTEM PROJECT X-20 (DYNA-SOAR). PROGRAM STATUS REPORT, 23 NOVEMBER - 12 DECEMBER 1963, December 1963, BAC-8233-933017, AD-434 005 (Unclassified).

Not abstracted.

1153. Bell Aerosystems Co., Buffalo, New York,
ROCKET DESIGN DATA HANDBOOK, SIXTH EDITION, January 1963, BA Misc 2 (Unclassified).

Not abstracted.

1154. Bendix Corporation, Southfield, Michigan,
RESEARCH AND EXPERIMENTAL VERIFICATION OF SUPER COMPONENT DESIGN TECHNIQUES APPLIED TO A COLD GAS REACTION CONTROLLER by B. R. Teitelbaum, July 1964, TDR-64-100, RLD-2620-A, AD-607 662, Contract AF-33(657)-10155 (Unclassified).

The study is concerned with the application of super component design techniques to a representative nonelectronic flight control component, and evaluation of the reliability improvement attained by means of tests performed on groups of standard and super units. The representative component used was a cold-gas proportional mode reaction controller for space vehicle attitude control applications. Three super controllers and four standard controllers were fabricated and were tested according to a plan which simulated, as far as was practical, a mission profile. The test results tended to show the super units had advantages over the standard units in regard to specific failure modes. However, no statistically significant difference in life characteristics between the two groups was demonstrated. This is attributed to the combination of the small numbers of samples in the test groups, and the relatively low magnitude improvement in life characteristics actually attained.

1155. Billet, A. B.,
SPACE VEHICLE CONTROL, Ordnance, Vol. 47, May-June 1963, pp. 674-677, A63-18120.

A discussion of current and future missile-control operational systems is included. A survey of the evolution in the environmental characteristics of missiles hydraulic controls is followed by a discussion of the utilization of hydraulic transmissions and servoactuated controls to provide the flexible control and response required for rendezvous and space-station missions. The application of a modified hydraulic control in a thrust-vector control installation is examined. Two types of secondary injection thrust-vector control systems (liquid injection, hot-gas injection) proposed for use in missiles and space vehicles are discussed, as is a novel thrust-control system which combines the two concepts of warm (2000°F) and hot (5000°F) gases to obtain the advantages of each. The mechanism by which liquid injection results in thrust control is illustrated.

1156. Billet, A. B.,
THRUST VECTOR CONTROL OPERATION IN COMBINED ENVIRONMENTS, Institute of Environmental Sciences, 1963 Annual Technical Meeting, Proceedings, Mt. Prospect, Illinois, Institute of Environmental Sciences, 1963, pp. 609-616.

A review of the present thrust-vector-control (TVC) systems for rocket engines, covering gimballed engines for TVC, jetavator, and hot-bleed systems is discussed. Each system is illustrated. Two types of secondary-injection TVC systems currently being considered in missile and space vehicles (liquid and hot-gas injection) are discussed, as are some of the environmental conditions under which this control equipment would be required to operate satisfactorily with present engines.

1157. Boeing Co., Seattle, Washington,
INFORMAL TRADE STUDY DATA REACTION CONTROL SYSTEM, July 1962, D2-80617, AD-433 271, Contract AF-33(657)-7132 (Unclassified).

Not abstracted.

1158. Boeing Co., Seattle, Washington,
REACTION CONTROL DISTRIBUTION LINE DEVELOPMENT TEST by R. H. Martin and R. M. Allen, January 1964, T2-2652, AD-432 921, Contract AF-33(657)-7132 (Unclassified).

Tests were performed to evaluate designs and materials for the hydrogen peroxide and nitrogen distribution lines used in the X-20 reaction control systems. The items tested include tubing, fittings, flexible hose, clamps, brackets, and insulation.

1159. Boeing Co., Seattle, Washington,
REACTION CONTROL SYSTEM - HYDROGEN PEROXIDE (U), March 1962, 10-81135, AD-348 691, Contract AF-33(657)-7132 (Confidential).

Not abstracted.

1160. Brown Engineering Co., Inc., Huntsville, Alabama
A COMPARATIVE ANALYSIS OF THE PERFORMANCE CAPABILITIES OF VARIOUS TYPES OF ELECTROSTATIC PROPULSION ENGINES by A. L. Cox, February 1965, TN-R-136, AD-613 047 (Unclassified).

The operating characteristics of three types of atomic ion engines and three types of colloidal ion engines are evaluated. The major theoretical factors which will limit payload capacity are brought out for each type of engine. Total propulsion system masses for the production of 10 pounds of thrust for 2000 hours and for 10,000 hours of engine operation are compared. Examination of the payload capacities of the various engines for several lunar and planetary missions shows that the colloidal ion engines have a superior payload capacity for lunar missions and may be competitive with atomic ion engines for planetary missions. The specific mass of the power supply system is shown to be a much more dominant factor in determining the payload capacities of the atomic ion engines than for the colloidal ion engines.

1161. Buckingham, A. G.,
PERFORMANCE OF AN ELECTROMAGNETIC ACTUATION SYSTEM, AIAA Journal, Vol. 1, February 1963, pp. 457-460.

Not abstracted.

1162. Cardullo, M. W.,
CHEMICAL ROCKET ENGINES FOR ATTITUDE CONTROL OF SPACE VEHICLES, American Rocket Society, Annual Meeting, 17th, and Space Flight Exposition, Los Angeles, California, 13-18 November 1962, Paper 2701-62, A63-12586.

Included is a discussion of chemical rocket-control engines from the standpoint of components incorporated into the system. The system is divided into three areas: propellants, pressurization and expulsion mechanisms, and engines and control. Propellants for attitude control are discussed as they affect overall performance. A method is presented for the use of hypergolic gases for low-temperature systems. Experimental work dealing with a new type of positive-pressure displacement system is presented. It is pointed out that the types of engines available (pulse, continuous, and controlled-thrust) are grouped according to the different types of energy management required. Experimental work with these various engine types is presented and their applications described. Redundancy tradeoffs for a typical attitude-control system for an orbiting vehicle are presented. It is shown that redundancy systems are basically only temporary means of increasing reliability. The basic solution can be achieved only by the development of more reliable components.

1163. Cardullo, M. W.,
CHEMISCHE RAKETENTRIEBWERKE FUER LAGEREGELUNGSSYSTEME VON RAUMFAHRZEUGEN, Raketentechnik u Raumfahrtforschung, Vol. 6, No. 4, October-December 1962, pp. 132-141.

Presented are chemical rocket engines and propulsion systems for attitude control and stabilization of space vehicles. Various components incorporated in the system are divided into propellants, pressurization and expulsions

system, engines and control. Most types of propellants available for attitude control systems and aspects of various pressurization schemes and their relation to the overall system are presented. Highest efficiency in attitude control can only be realized by use of small rocket engines with either pulse, continuous or controlled thrust.

1164. Defense Documentation Center, Alexandria, Virginia, ELECTRIC PROPULSION, A CUSTOM ABSTRACT SEARCH, REPORT FOR JANUARY 1953 - MARCH 1963 by G. E. Chapman, June 1963, DDC ARB-17527, AD-406 850 (Unclassified).

A bibliography is presented of 259 unclassified references on electric propulsion including: 38 general electric propulsion, 15 arc-jet, 142 ion, 6 photon, and 58 plasma engines.

1165. Dobronravova, B., CONTROL OF COSMIC SHIP (Foreign title not available), Translated into English from Czechoslovakia, Dridla Vlasti, No. 11, 29 May 1963, pp. 322-323 by Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, FTD-TT-63-718/1 + 2, 23 July 1963, AD-414 836, N64-16386.

Spacecraft control mechanisms for navigation, orientation, maneuver, and stabilization are summarized.

1166. Donlin, T. J. and Randall, J. C., SOLAR VANE ACTUATION SYSTEM FOR SPACECRAFT ATTITUDE CONTROL, ASME Paper 64-MECH-40, 19-21 October 1964.

Functions and detail design of actuation system for solar pressure vanes for passive spacecraft attitude control are described. Actuation system consists of an electromechanical system which moves vanes to balance solar pressure on spacecraft, and thermal-mechanical system which introduces solar pressure damping. Both systems are discussed in detail with parameters for specific spacecraft. Techniques established can be directly applied to any spacecraft configuration.

1167. Electro-Optical Systems, Inc., Pasadena, California, APPLIED RESEARCH ON CONTACT IONIZATION THRUSTER, VOLUME II, MISSION ANALYSES, FINAL REPORT, MARCH 1963 - MARCH 1964 by R. S. H. Toms, May 1964, TDR-64-52V2, AD-601 187, Contract AF-33 (657)-10980 (Unclassified).

Possible early applications of ion thrusters were investigated to give direction to the advancing technology in thrusters and associated power conditioning, control and feed systems, approximate methods of calculating performance and first order space flight mechanics have general application to a wide variety of low-thrust studies. An exhaustive survey of thrusting modes was performed using the new techniques. Missions using solar-electric power and nuclear-electric power were considered. It was concluded that the most attractive application for solar-electric rockets is the 24-hour satellite. For the nuclear-electric rocket an advanced orbital space station, a group of unmanned probes, and all manned missions beyond the moon are highly competitive.

1168. Electro-Optical Systems, Inc., Pasadena, California, ION THRUSTOR PROGRAM, FINAL TECHNICAL REPORT, October 1965, APL-TR-65-87, EOS-2020-4260, AD-472 336, Contracts AF-33(657)-7285, AF-33(615)-1032, and AF-661A (Unclassified).

The complete history of the development of the ballistic flight test ion engine program with extensive analysis of the two successful ballistic flight tests in August and December 1964 is covered in this report. The objectives of this program are: (1) Development of ion thruster systems suitable for space flight testing. (2) Integration of these systems with various vehicle payloads. (3) Provision of technical services required to support the flight tests. (4) Detailed analysis of flight test results. The electronics system development is given extensive treatment. Types of failure modes are discussed, together with the measures taken to ensure the reliability of the electronics system. The systems testing phase is covered in detail. The most important part of this report deals with the flight test results from the second ballistic flight test and, to a lesser degree, from the third flight. The ion engine operation, the effect of neutralization, and the vehicle potential are thoroughly described.

1169. Farron, J R.,
DEVELOPMENT OF EXTENDED DURATION 1200 °F TORQUE MOTOR, ASME Paper 62-AV-2, 26-28 June 1962.

Discussed are application of high performance fluid power servos for attitude and engine control functions to advanced flight vehicles and requirements of hydraulic systems with regard to their sensitivity to environmental conditions. Development and evaluation of a torque motor representing the first component developed is also discussed. The motor consists of electromagnetically polarized "E-Dot" type magnetic circuit in which the armature is supported by thin-walled, tubular, cantilever spring; performance characteristics and test results are obtained.

1170. Garnjost, K. D. and Thayer, W. J.,
NEW SERVOVALVES FOR REDUNDANT ELECTROHYDRAULIC CONTROL, American Institute of Chemical Engineers, 1963, A64-11180, p. 43 (International Federation of Automatic Control, Congress, Basel, Switzerland, 21 August - 4 September 1963).

Included is a review of the application of redundancy to electrohydraulic servovalves used in critical functions such as in space vehicles. Considered are the monitor servovalve, in which a failed element is detected by an appropriate sensor and a good element is switched to replace it, and the majority voting servovalve, in which the effect of a failed element is directly overpowered or "outvoted" by a majority of unfailed elements.

1171. Gaylord, R. S.,
DIFFERENTIATING GAS JET FOR SPACE ATTITUDE CONTROL, ARS Journal, Vol. 31, January 1961, pp. 75 and 76.

Not abstracted.

1172. Geideman, W. A., Jr. and Muller, K.,
DEVELOPMENT STATUS OF LOW-POWER ARC-JET ENGINES, Journal of Spacecraft and Rockets, Vol. 2, No. 5, September-October 1965, pp. 718-723.

Results of continuous performance test of 2-kw arc-jet thruster and design concepts that were employed to obtain thruster design are presented. The thruster is a revised version of an earlier 1-kw thruster design. In addition, results of pulsed-mode test on 1-kw thruster are presented. Continuous lifetime of 150 hour without failure of thruster has been demonstrated. The same thruster has been operated at specific impulse levels as high as 1270 seconds and at input power levels up to 3.5 kw. In pulsed-mode operation, 17,580 hot thrust pulses were achieved in test.

1173. General Electric Co., Philadelphia, Pennsylvania,
RESEARCH AND INVESTIGATION ON SATELLITE ATTITUDE CONTROL, PART III, POWER SOURCES, TECHNICAL REPORT by W. C. Flanigan, March 1965, TR-64-168-PT-3, AD-469 206 (Unclassified).

A search of the literature in the field of space power has been conducted. Most of the more promising subsystems that use satellite electrical power systems were investigated in detail and are discussed. Pertinent data of those systems expected to be available in the 1964-1966 time period are presented. Data are presented in parametric form wherever feasible, to lend itself more readily to use by space vehicle designers.

1174. George Washington University, Washington, D. C.,
TESTING OF A NIMBUS ATTITUDE CONTROL NOZZLE AT SIMULATED ALTITUDES OF 400,000 TO 500,000 FEET by C. E. Cheeseman, October 1964, TDR-64-210, AD-449-864, Contract AF-40(600)-1000 (Unclassified).

A test was conducted in a seven-foot-diameter space chamber to determine the jet plume properties of a 200:1-area-ratio nimbus attitude control nozzle. The chamber was equipped with a large 20-k cryoarray which maintained ambient pressures of 10^4 to 10^6 torr during sustained nozzle operation. Argon, nitrogen, carbondioxide, and freon-14 plume properties were determined by measuring forces on a

normal flat plate at various positions in the plume. Glow discharge illuminated photography was employed to visualize the flow.

1175. Granan, J. R., et al,
LIQUID METAL HYDRAULIC FLUIDS EXTEND FLIGHT CONTROL SYSTEM OPERATION TO 1400°F, Society of Automotive Engineers Journal, Vol. 70, October 1962, pp. 44-52.

Not abstracted.

1176. Haloulakos, V. E.,
THRUST AND IMPULSE REQUIREMENTS FOR JET ATTITUDE-CONTROL SYSTEMS, Journal of Spacecraft and Rockets, Vol. 1, January-February 1964, pp. 84-90, A64-14330 (American Institute of Aeronautics and Astronautics, Summer Meeting, Los Angeles, California, 17-20 June 1963, Paper 63-237).

Not abstracted.

1177. Himmler, C. R.,
MEASUREMENTS OF THE STATIC AND DYNAMIC BEHAVIOR OF ELECTROHYDRAULIC GUIDANCE SYSTEMS FOR ROCKETS AND CONSIDERATION OF POSSIBLE OPTIMAL VALUES (Mesures sur le Comportement Statique et Dynamique des Systemes de Guidance Electrohydraulique Pour Engins et Considerations sur les Valeurs Optima Possibles), Braunschweig, Friedr. Vieweg and Sohn, 1962, pp. 323-328 (In French with summaries in English and German), A63-21865 (WGL Tagung, Freiburg im Breisgau, Germany, 10-13 October 1961; Wissenschaftliche Gesellschaft fur Luftfahrt E. V., Jahrbuch, 1961).

Included is a discussion of navigational control of guided rockets based on electrodynamic systems. It is shown that the fast response of hydraulic motors and the low time constant of two-stage hydraulic amplifiers give excellent performance.

1178. Hughes Aircraft Co., Culver City, California,
ELECTRIC PROPULSION FOR CONTROL OF STATIONARY SATELLITES by R. Boucher, 1963, 63009, AD-406 682, (Presented at AIAA Electric Propulsion Conference 11-13 March 1963, Colorado Springs, Colorado) (Unclassified).

The application of electric propulsion engines to attitude control and station keeping of 24-hour stationary satellites is analyzed and compared with the performance of contemporary cold gas, monopropellant, and bipropellant propulsion systems. Both a 500-pound spin stabilized and a 1500-pound three-axis controlled satellite compatible with current NASA boost vehicles are examined. Each type of propulsion system is compared as a function of mission duration and maneuver requirements. Solar electric propulsion is shown to be superior to chemical propulsion for long-term station keeping and three-axis attitude control of the larger satellite. Cold gas and chemical propulsion are superior for attitude control and provide strong competition for electric propulsion in the station keeping of the smaller spin-stabilized satellite.

1179. Interagency Chemical Rocket Propulsion Group, Design Engineering Working Group,
HIGHLIGHTS OF DESIGN AND ENGINEERING (U), December 1965, ICRPG/DEWG HDE Vol. 2, No. 4 (Confidential).

Not abstracted.

1180. Kane, T. R. and Mingori, D. L.,
EFFECT OF A ROTOR ON THE ATTITUDE STABILITY OF A SATELLITE IN A CIRCULAR ORBIT, AIAA Journal, Vol. 3, May 1965, pp. 936-940.

Not abstracted.

1181. Kibby, B. G., et al,
GAS SAVES WEIGHT: GIVES STABLE FLIGHT, Society of Automotive Engineers Journal, Vol. 70, October 1962, pp. 80-82.

Not abstracted.

1182. Kidde (Walter) and Co., Inc., Belleville, New Jersey, SURVEY OF SPACE VEHICLE HOT/COLD GAS POWER SUPPLIES FOR ACTUATION AND FLIGHT CONTROL FOR DEPARTMENT OF THE NAVY BUREAU OF NAVAL WEAPONS, FINAL REPORT, December 1963, R1635, AD-439 725, Contract NOw61-0127F (Unclassified).

The purpose of this study is to survey the need for and use of systems employing hot and cold gas power for flight control and mechanical actuation on missiles and space vehicles. The requirements of various vehicle types are cataloged and a comparision of the relative merits of candidate systems is made. Flight control of missiles and space vehicles goes far beyond cable operated aerodynamic surfaces employed in aircraft. Its scope encompasses the broad functions of attitude control and stabilization, main engine thrust vectoring, orbit correction, velocity adjustment, rendezvous and docking manuevering, acceleration for propellant bottoming action, and other secondary propulsion functions. Because the control functions are numerous as are the vehicle types and missions, there are many potential combinations to be evaluated. This report reviews the vehicle requirements, examines the capability of the various types of power systems, and attempts to match these characteristics to produce an optimum system selection for each mission while providing the necessary service.

1183. Kooy, J. M. J., ON DYNAMICS OF SPACE VEHICLE, EQUIPPED WITH ONE MAIN ROCKET MOTOR AND TWO VERNIER MOTORS, Astronautica Acta, Vol. 6, No. 6, 1960, pp. 322-341.

A general theory of rotary motion of a rocket vehicle is developed. Also discussed is how to determine the motion of a vehicle if two angles defining the relative direction of main thrust and angle defining adjustment of a pair of Vernier motors, and magnitudes of three thrusts are prescribed as a function of time.

1184. Kretschmer, W. K., SMALL BIPROPELLANT ROCKET FOR SPACECRAFT ATTITUDE CONTROL, Space Aeronautics, Vol. 37, April 1962, p. 187.

Not abstracted.

1185. Langer, R. M. and Vinti, J. P.,
DRAG COMPENSATION AND MEASUREMENT WITH MANNED SATELLITES, FEASIBILITY STUDY, Journal of Research, Engineering and Instrumentation, Vol. 67C, No. 3, July-September 1963, pp. 247-249.

Even at low altitudes approximating those of manned earth-satellites, it is feasible to use external jets to maintain satellites in purely gravitational orbit. With jets off, it is possible to measure drag, air density, and time of passage through perigee, by means of observations aboard the satellite. Intermittent operation of jets should permit achievement of both objectives.

1186. Laub, J. H. and McGinness, H. D.,
GAS-FLOATED SPINNING SPHERES, Aerospace Engineering, Vol. 20, December 1961, pp. 26-27.

Not abstracted.

1187. Lieberman, S. L.,
BANG-BANG ATTITUDE CONTROL SYSTEM FOR SPACE VEHICLES, Aerospace Engineering, Vol. 21, October 1962, pp. 54-55.

Not abstracted.

1188. Litvin-Sedoy, M. Z.,
CONTROL OF ANGULAR MOTION OF A BODY BY MEANS OF ROTORS, AIAA Journal, Vol. 1, January 1963, pp. 275-277.

Not abstracted.

1189. Maclaren, A. P.,
A GAS-JET ATTITUDE-CONTROL SYSTEM FOR SATELLITES. II, Control (GB), Vol. 8, October 1964, pp. 521-525.

This study considers the two (phase advance and feedback, respectively) on/off systems. Initial stabilization of residual spins after injection is of considerable importance, as this stage may demand greater thrusts than are necessary for normal operation. Trajectories for both systems are drawn after making allowance for some practical constraints.

After initial stabilization, the satellite will oscillate continuously with an amplitude dependent on the size of the dead zone. The effect of sensor noise and disturbing torques are investigated for both systems, and it is concluded that, although the feedback system is much less wasteful of gas in the presence of sensor noise than is the phase advance system, a bias error, due to a steady disturbing torque will occur in the feedback system, but the effects may not be too serious.

1190. Marquardt Corporation,
INFORMATION ON REACTION SYSTEMS FOR SPACE VEHICLE CONTROL, Marquardt PSD 1053 (Unclassified).

This a brief summary and description of Marquardt activity in the reaction control field. Parametric curves, summary data, and component characteristics are included for system design assistance.

1191. Marquardt Corporation,
INFORMATION ON REACTION SYSTEMS FOR SPACE VEHICLE CONTROL PRELIMINARY DESIGN STUDY #1053, Marquardt PDS 1053 (Unclassified).

The Marquardt Corporation initiated a program of space vehicle guidance and control in 1958. The information presented in this report represents a brief summary and description of Marquardt activity in the reaction control field as a result of both contractural and company-sponsored programs. Parametric curves, summary data, and component characteristics are included for system design assistance.

1192. Massachusetts Institute of Technology, Cambridge, Massachusetts,
BASIC APPLIED RESEARCH IN FLUID POWER CONTROL by S. Y. Lee, MIT/DSR 5393-1, FDL-TR-65-79, Contract AF-33(615)-2210 (Unclassified).

Not abstracted.

1193. Massachusetts Institute of Technology, Cambridge, Massachusetts,
BASIC APPLIED RESEARCH IN FLUID POWER CONTROL, SEVENTH PROGRESS REPORT, 1 OCTOBER 1963 - 31 JANUARY 1964 by S. Y. Lee and H. H. Richardson, 2 June 1964, Report 8998-7, FDL-TDR-64-72, N64-26886, AD-603 195, Contract AF-33(657)-7535 (Unclassified).

High-performance fluid control devices for advanced aerospace systems are discussed. Continued emphasis is placed on pneumatic components and systems capable of performing over wide ranges of temperature and in the presence of intense radiation. This report describes work with a new pulse actuation system, a pneumatic pulse-length-modulated servo system, a gas-operated accelerometer, the dispersion of transients in fluid transmission lines, a new electrostatic pure fluid jet valve, a dirt-insensitive flapper valve, and gas-lubricated bearings.

1194. Melcher, H. J. and Otten, D. D.,
MODULATING BANG-BANG ATTITUDE CONTROLS, Control Engineering, Vol. 12, November 1965, pp. 73-75, A66-13206.

Included is a description of a thrust modulation system which provides a minimum limit cycle in a fully effective bang-bang system for the purpose of reducing fuel consumption. A single-axis attitude control system replaces a conventional relay with a thrust modulator having a dead zone limiter, a simple time integration, and a switching element with hysteresis. The output of the relay is fed back to the input of the integrator to cancel the error signal from the limiter. The result is a combination pulse duration and pulse frequency modulation of the constant-thrust gas jet. Two thrust modulator circuits briefly described have been constructed and tested and experimental results agree very closely with the theoretical.

1195. Miksch, R. S. and Heller, K. G.,
DESIGN AND DEVELOPMENT OF A VAPORJET ATTITUDE-CONTROL SYSTEM FOR SPACE VEHICLES: ABSTRACT, Space/Aeronautics, Vol. 39, April 1963, pp. 116-119.

Not abstracted.

1196. Miksch, R. S. and Heller, K. G.
VAPOR JETS FOR SPACECRAFT ATTITUDE CONTROL, Space/Aeronautics, Vol. 39, April 1963, pp. 116-119, A63-14309 (U. S. Air Force Systems Command, Aeronautical Systems Division, ASD TR-61-471, 1962).

Included is a description of a vapor-jet system that provides a lower thrust level of 0.001 lb and an upper thrust level of 0.1 lb, employing vapor pressures of 1 and 10 psia, respectively, The low-thrust jet employs water vapor and the high-thrust jet uses propane. Since a two-phase system is used, the liquid and vapor phases are separated by a semipermeable membrane, and the liquid phase is pressurized with propyl acetate liquid. Discrete corrective impulses are applied when the vehicle attitude or angular rate exceeds a preset value. Attitude is controlled to within ±0.5 degree.

1197. Muraszew, A.,
THE STATE-OF-THE-ART IN BIPROPELLANT REACTION-CONTROL SYSTEMS, American Society of Mechanical Engineers, Aviation and Space, Hydraulic, and Gas Turbine Conference and Products Show, Los Angeles, California, 3-7 March 1963, Paper 63-AHGT-50, A63-17598.

Included is a discussion of the state-of-the-art in bipropellant reaction control systems, using storable propellants based on N_2O_4 as oxidizer and N_2H_4-UDMH mixture as fuel. An approach to high system reliability, combined with high performance and low weight is considered. A detailed description is given of bipropellant attitude-control rockets of both radiation-cooled and ablation-cooled types in terms of rocket performance, materials used, and fabrication techniques. Propellant tanks with positive expulsion devices are also described. Both teflon bladders and metallic bellows are discussed in the positive expulsion of propellants in the zero-g field. The state-of-the-art in system valves is briefly reviewed.

1198. National Aeronautics and Space Administration, AERODYNAMIC INTERACTION EFFECTS AHEAD OF SONIC JET EXHAUSTING PERPENDICULARLY FROM FLAT-PLATE INTO MACH NUMBER 6 FREE STREAM by D. J. Romeo and J. R. Sterrett, April 1961, NASA Technical Note D-743 (Unclassified).

Use of jet reaction devicer as means of space vehicle control outside of atmosphere is investigated. The ratio of jet stagnation pressure to free stream static pressure was varied from 8 to 460 and jet slot width from 0.001 to 0.05 inch. The ratio of aerodynamic to pure jet reaction force was sizable and varied from 0.5 to 9. The ratio increased with increasing pressure ratio and decreasing slot width.

1199. National Aeronautics and Space Administration, CHARACTERISTICS OF SMALL CONTROL ROCKETS (U) by J. F. Connors and W. T. Latto, Jr., January 1962, NASA TM-X-480 (Confidential).

Not abstracted.

1200. National Aeronautics and Space Administration, MEASURED STEADY-STATE PERFORMANCE OF WATER VAPOR JETS FOR USE IN SPACE VEHICLE ATTITUDE CONTROL SYSTEMS by B. E. Tinling, May 1962, NASA TN D-1302 (Unclassified).

Measurements have been made in a vacuum environment to determine the steady-state performance of several nozzles having thrusts up to 1000 dynes for use in space vehicle attitude control systems. Water vapor was used as a propellant. The results indicate that the trend of the variation of specific impulse and thrust coefficient with expansion ratio is predicted by calculations based on one-dimensional isentropic flow. The level of these quantities, however, is dependent upon the nozzle diameter. The specific impulse varies from about 30 percent to 80 percent of the theoretical value as the nozzle that is increased from about 10 to 1000 dynes.

1201. National Aeronautics and Space Administration,
ON OPTIMALITY OF TOTALLY SINGULAR VECTOR CONTROL, EXTENSION OF GREEN'S THEOREM APPROACH TO HIGHER DIMENSIONS by G. W. Haynes, September 1965, NASA CR-305 (Unclassified).

Extension of Green's theorem approach to higher dimensions has been derived for determination of optimality of totally singular vector controls governing n dimensional nonlinear systems with (n-1) dimensional vector control appearing linearly. The essential condition that motivates analysis is that coefficients of vector control, when viewed as tangent vectors, form complete system of partial differential equations of order (n-1).

1202. National Aeronautics and Space Administration, Lewis Research Center, Cleveland, Ohio,
APPLICATIONS OF LOW-POWER NUCLEAR ROCKETS by F. E. Rom, 1964, NASA-TM-X-52048, X64-36377 (Presented at the Second Lecture Series on Nuclear and Electric Rocket Propulsion, Brussels, 28 September - 3 October 1964) (Unclassified).

Not abstracted.

1203. National Aeronautics and Space Administration, Lewis Research Center, Cleveland, Ohio,
ELECTRIC PROPULSION - 1965 by J. C. Evvard, 1966, NASA-TM-X-57074, X66-35370 (Unclassified).

Not abstracted.

1204. National Aeronautics and Space Administration, Lewis Research Center, Cleveland, Ohio,
INTERPLANETARY FLIGHT WITH ELECTRIC PROPULSION by J. S. MacKay and W. R. Mikelsen, 28 September 1964, NASA-TM-X-54831, X65-35036 (Unclassified).

Not abstracted.

1205. National Aeronautics and Space Administration, Lewis Research Center, Cleveland, Ohio,
STATUS OF ELECTROSTATIC THRUSTERS FOR SPACE PROPULSION by W. R. Mikelsen and H. R. Kaufman, May 1964, NASA TN D-2172, N64-19477 (Unclassified).

Current research programs are described for electron-bombardment thrusters, contact-ionization thrusters, and colloidal-particle thrusters. The critical component in the electron-bombardment thruster is the cathode, and recent data indicate that durable, low-power cathodes can be developed. The performance of the contact-ionization thruster is severely limited by porous-tungsten technology. Colloidal-particle thrusters are still in the research stage but appear to have the best promise for high efficiency at low specific impulse, low mass, and programmed specific impulse operation.

1206. National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama,
A DESIGN OF ELECTRIC MACHINERY FOR LONG TIME ATTITUDE CONTROL OF SPACE VEHICLES by D. L. Teuber, 25 February 1963, NASA TM X-51373, MTP-ASTR-R-63-3, N64-13064 (Unclassified).

An actuator is described that is to work in a control system in which an angular impulse acting on a vehicle is counteracted by the acceleration of a flywheel in each of three mutually perpendicular axes. The system will work in a vacuum and provide a torque proportional to the sum of error and rate of error signal. The concept of the electronic commutator eliminates brushes; the position of the rotor with respect to the stator windings is sensed and energized through an amplifier system that switches the corresponding stator winding. A high efficiency is obtained by matching back electromotive force (EMF) and applied voltage in four concentrated windings in addition to the use of a permanent magnet and a relatively wide airgap. The desired control characteristic of a torque independent of motor speed but proportional to a signal is achieved by feedback loops and a constant current output of a dc/dc inverter.

1207. National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama,
PERFORMANCE COMPARISON BETWEEN VARIABLE THRUST AND CONSTANT THRUST ELECTRIC PROPULSION SYSTEMS FOR MARS FLYBY AND EARTH ESCAPE MISSIONS by J. A. Downey, III, S. A. Fields, and E. Stuhlinger, X64-35289 (In NASA, Washington Trajectories and Mission Analysis, July 1963, pp. 77-90, X64-35283) (Unclassified).

Not abstracted.

1208. Neiland, V. R. and Kalange, M. A.,
FLUID FLIGHT CONTROL SYSTEM ON TAP FOR SATURN
Society of Automotive Engineers Journal, Vol. 71, May 1963, pp. 62-66.

Not abstracted.

1209. North American Aviation, Inc., Downey, California,
ROCKET ENGINE, APOLLO SERVICE MODULE REACTION CONTROL, MC901-0004B, IDEP-563-00-00-00F1-01, AD-421 264 (Unclassified).

The technical requirements are presented for a liquid propellant rocket engine to be employed for attitude control and stabilization of the Apollo spacecraft service module.

1210. North American Aviation, Inc., Downey, California,
ROCKET ENGINE, BIPROPELLANT APOLLO COMMAND MODULE REACTION CONTROL by K. White, November 1962, MC901-0067A, IDEP-563-00-00-00F1-02S, AD-421 266 (Unclassified).

The technical requirements are presented for a liquid propellant rocket engine to be employed for attitude control and stabilization of the Apollo spacecraft command module.

1211. North American Aviation, Inc., Autonetics Division, Downey, California,
PBPS ANALYSIS REPORT, November 1965, C5-1987/319, AD-474 058 (Unclassified).

Thermal analysis of engines and thrusters is in progress. The preliminary results for five-pound thrust engines are

shown in graphical form. A detailed plan for system dynamic analysis is presented. The analysis of all factors which affect delivered performance variability is part of this task. The ignition and combustion characteristics of the propellants have been surveyed. No problems are anticipated in this area, based on comparisons of theoretical data with presently available experimental results.

1212. Pennsylvania State University, University Park, Pennsylvania, RESEARCH AND DEVELOPMENT OF ON BOARD CONTROL SYSTEMS AND ELEMENTS FOR AEROSPACE VEHICLES, RESEARCH REPORT NO. 2 by J. C. Tamulis et al, October 1965, NASA-CR-68101, N66-12186, Grant NGR-39-009-023 (Unclassified).

The following studies are reported: (1) Signal Noise in Fluid Amplifiers - large scale fluid amplifier, free jet apparatus, associated measuring and recording devices, and analytical and theoritical studies of proportional pure fluid pressure amplifiers. (2) Pneumatic Stepping Motor - initial development tests of prototype pneumatic motor. (3) Hydraulic Stepping Motor - analog computer studies of changes in geometry, mass, and power requirements. (4) Experimental Electric Servo Motor - design configuration of high performance dc motor. (5) Hysteretic Nonlinearities in Closed Loop System - development of switching logic to eliminate instability. (6) Dynamics of Fluid Transmission Lines - frequency estimation by using models of the matrix transfer function, and of a linear lumped parameter using electrical network theory. (7) Some Unusual Analog Computer Circuits - circuits for spatial integration, etc. (8) Steam-To-Air Energy Converter - free piston concept. (9) Fluid Amplifier Pressure Sensor - analytical modeling of devices for incorporation into engineering systems.

1213. Philipson, J.
CONTROL ROCKETS IN SPACEFLIGHT TECHNOLOGY (Hilfsraketen in der Raumfahrttechnik), Weltraumfahrt, Vol. 14, January-February 1963, pp. 5-13, A63-14916 (In German).

Included is a discussion of control rockets and their characteristics. The functioning of control rockets is described for orbit-correction maneuvers, attitude stabilization, last-stage separation, and capsule deceleration. Methods used to achieve redundancy and reliability of control rockets

are outlined, as are the principles of operation of solid-propellant control rockets. The Atlas retrorocket, 1 KS 380, is examined in some detail. Some results of control rocket test programs are tabulated.

1214. Pohl, H. O.,
REACTION-CONTROL SYSTEMS, New York, Fairchild Publications, Inc., 1964, pp. 287-296, A65-12557.

Included is a description of reaction-control systems (RCS) which provide impulses for positioning and rotating spacecraft in space. The basic control requirements are noted. The different types of control devices, including reaction jets, solar jets or magnetic torquers, and momentum-transfer devices, are briefly described, with emphasis on the jet RCS. An expression for the propellant weight required for limit-cycle operation of a jet RCS is derived. Propellant sources are described, including pressurized gas, mono-propellants, and bipropellants. The design of jet RCS thrusters, injectors, and injector valves are discussed. Reliability considerations are presented.

1215. Rand Corporation, Santa Monica, California,
A STUDY OF ELECTRICAL PROPULSION IN THE SPACE PROGRAM by B. Pinkel and D. L. Trapp, P-2881-1, AD-607 265 (Unclassified).

Electrical propulsion systems in space flight are compared with other systems, particularly for the parameters of specific mass and operational endurance. Reliability, developmental time, and costs of elective propulsion are discussed.

1216. Research and Advanced Development Division, Avco Corporation, Wilmington, Massachusetts,
WEAPON SYSTEM 107A-2, THE ARC-JET-PROPELLED SPACE VEHICLE, March 1961, SR61-27, Vol. 1, AD-445-488, Contract AF-04(647)-305 (Unclassified).

This report treats the status of the studies performed to date on an arc-jet-propelled space vehicle. The concepts presented herein are applicable to a variety of missions in Earth orbit, cis-lunar, and lunar space. As an example of the capabilities of such a vehicle, a lunar reconnaissance and mapping mission is treated in greater detail than the other possible missions.

1217. Roach, R. D., Jr.,
ROCKET SYSTEMS FOR SPACE-VEHICLE STABILIZATION AND MANEUVERABILITY, ASME Paper 62-AV-37, 26-28 June 1962.

This paper discusses: design and development of rocket type, reaction control systems developed by Bell Aerosystems Co.; system requirements and design of various propellant system (monopropellants and liquid and gaseous bipropellants); program experience in design and operational usage on X-15 and Mercury space capsule; illustrates variety of reaction control systems currently operational. Research and development efforts indicating novel component designs for radiation cooled thrust chambers are discussed.

1218. Romaine, O.,
SECONDARY ROCKETS, Space/Aeronautics, Vol. 39, May 1963, pp. 83-89, A63-18828.

Included is a discussion of the various types of secondary thrust devices developed for attitude control and stabilization, orbit changes, trajectory corrections, and rendezvous of space vehicles. Covered are such characteristics as thrust levels, type of propellant used, number of functions performed, type and degree of controllability and thrust variation, and type of cooling.

1219. Romaine, O.,
SECONDARY ROCKETS COVER WIDE SPECTRUM IN PERFORMANCE AND APPLICATION, Space/Aeronautics, Vol. 39, No. 5, May 1963, pp. 83-89.

Secondary thrust covers all forms of spacecraft thrust other than those supplied by the main power plant of the launch vehicle. Thus, it includes attitude control and stabilization, coplanar and interplanar orbit changes, trajectory correction, rendezvous etc. Types of thrust devices, i.e., reaction control systems, restartable motors, and solid-propellant motors used for stage separation, ullage settling, reentry, etc; factors to consider in selection of device; details of Mercury and Gemini systems are discussed.

1220. Romaine, O.,
WHY EXPLOSIVE DEVICES? Space/Aeronautics, Vol. 39, March 1963, pp. 96-99.

Not abstracted.

1221. Royal Aircraft Establishment, Farnborough, England, SOME DESIGN PARAMETERS FOR LOW THRUST GAS JET CONTROL SYSTEMS, TECHNICAL REPORT by B. P. Day, February 1965, TR-65014, AD-463 207 (Unclassified).

Satellite jet control valve and nozzle discharge coefficients were measured for air and propane. The pressure rise time in the valve to nozzle interspace was measured and the results correlated with theoretically predicted values.

1222. Royal Aircraft Establishment,Farnborough, England, THE ENLARGEMENT OF ELLIPTIC SATELLITE ORBITS BY CONTINUOUS MICRO-THRUST by D. G. Kinghele, July 1963, RAE Technical Note Space 38, AD-419 570 (Unclassified).

The orbital changes are considered which occur when a small tangential thrust is applied continuously to a satellite initially in an elliptic orbit with eccentricity less than 0.2. Analytical expressions are derived for the variation of semi-major axis A, with eccentricity and the variations of both of these quantities with time. The thrust/mass ratio is assumed to be constant or to vary linearly with time. It is found that E is approximately proportional to $1/A^{3/2}$, so that E decreases towards zero as A tends to infinity. If the thrust/mass ratio is nearly constant, E decreases almost linearly with time. Simple expressions are obtained for the time to reach escape velocity and for the number of revolutions completed at any given time. A numerical example shows that, with a thrust acceleration of 10^{-4} g_0 (g_0 = 9.81 m/sec^2), a satellite in a close orbit about the earth (with A = 8000 km) would take 47 days to transfer to a 24-hour circular orbit. The continuous-thrust transfer is compared with the two-impulse hohmann transfer, and a simple formula is obtained for the ratio of the total velocity "impulses" required.

1223. Ruhle, F.,
THE CONTROL OF SATELLITE VEHICLES (Die Steuerung von Raumflugkörpern), Astronomie und Raumfahrt, No. 5-6, 1963, pp. 173-190, A64-26648 (In German).

General discussion of the problem of control of manned and unmanned space vehicles are discussed. First, control functions in various space missions are tabulated and concepts of satellite control and guidance are defined. The physical principles of motion in space are then treated mathematically, covering basic dynamic equations and aerodynamic and other forces and moments acting on a space vehicle.

1224. Ryan, R. L. and Clark, R. A., Jr.,
COMPARISON OF ATTITUDE CONTROL TORQUERS FOR TRANSORBITAL MISSIONS, American Insitutte of Aeronautics and Astronautics, Electric Propulsion Conference, Colorado Springs, Colorado, 11-13 March 1963, Paper 63037, A63-15458.

Included is a comparison of the available attitude-control torquing systems on the basis of weight and reliability considerations. To illustrate a general approach to the problem, the attitude-control torquer system weight for a variety of space missions is considered. Vehicle disturbances are discussed and their magnitudes and resultant momentum requirements are compared. For example, the estimated magnitude of the disturbances encountered during the geocentric and heliocentric portion of interplanetary missions - e.g., gravitational effects, magnetic fields, and solar pressure are based on a survey of what is considered to be the best available data. Calculations for mission duration are based on the Irving-Blum method. On the basis of the study, it is concluded that the most desirable system for an interplanetary mission of up to two years' duration is a combination of electric engines backed up with a cold gas system.

1225. Sandeman, E. K.,
CRITERION FOR ANGULAR NOISE IN STAR-LOCK SYSTEMS, IRE Transactions on Aerospace and Navigational Electronics, Vol. ANE-9, No. 1, March 1962, pp. 21-23.

It is shown that for given signal-to-noise power ratio for any steady deviation of parameter from its required value in closed-loop linear servo system, actual rms variation of parameter from its required value due to noise cannot exceed certain rms value. Determination of this value and its use as criterion of noise in servo system is discussed.

1226. Schmidlin, A. E.,
GAS SYSTEM DEVELOPMENTS, Hydraulics and Pneumatics, Vol. 14, December 1961, pp. 72-73.

Not abstracted.

1227. Starrett, P. S. and Halfpenny, P. F.,
IMPULSE BIT MEASUREMENT FOR SMALL PULSED ROCKET MOTORS, AIAA Journal, Vol. 1, July 1963. pp. 1679-1681.

Not abstracted.

1228. Sung, C. B. and Schaffer, D. J.,
TECHNOLOGICAL INTEGRATION IN DYNAMIC CONTROLS, SAE Paper 593C, 8-12 October 1962.

Designer must work towards optimum design through direct integration of all available dynamic control techniques with propulsive and/or nonpropulsive power sources, environmental conditions or controls, and critical design parameters of space vehicle. Available techniques for controls include electrical, hydraulic, mechanical, pneumatic, and hybrid. Applications of techniques to various dynamic control functions as a result of better system integration are illustrated; four major requirements to achieve proper integration in dynamic controls are discussed.

1229. Sung, C. B. and Taplin, L. B.,
AEROSPACE PNEUMATIC CONTROL SYSTEMS, ASME Paper 62-AV-1, 26-28 June 1962.

This paper attempts to deduce a growth pattern of aerospace pneumatic control systems, where pneumatic systems are defined as those employing any gas as a working medium. Illustrations of applications, such as nuclear engine controls, space attitude controls, and flight controls are covered. Scope of control systems and their inherent characteristics in terms of capabilities and limitations, review of configurations of control systems and key components, and evaluation of system status and future position are discussed.

1230. Sutherland, G. S. and Maes, M. E.,
A REVIEW OF MICROROCKET TECHNOLOGY - 10^{-6} TO 1-LBF THRUST, American Institute of Aeronautics and Astronautics, Propulsion Joint Specialist Conference, Colorado Springs, Colorado, 14-18 June 1965, Paper 65-620, A65-26763.

A survey of a new and specialized branch of rocketry, generally referred to as microthrust or microrocket technology is discussed. Covering the thrust range from roughly 10^{-6} to 1 lbf, and utilizing solid, liquid, and gaseous propellants, these systems provide small reaction forces for spacecraft control. Typical applications include limit cycle attitude control, spin axis precession, spin rate control, inversion maneuvers, orbit adjustment and station keeping, drag makeup, and reaction wheel unloading. Low thrust and minimum impulse bits require minute propellant flow rates, rapid response, and low operating pressures. Requirements for long life in space place particular emphasis on simplicity and reliability. New techniques are in use or under development which, compared to conventional cold gas units, offer improvements in performance, flexibility, useful life, and reliability. Propellants employed include gaseous and liquid bipropellants, solid propellants hydrazine and hydrogen peroxide monopropellants, subliming solids vaporizing liquids, and stored gas. Unique microrockets using these materials are under development, such as the valveless subliming solid, the solid propellant "cap pistol," and the resistojet. Accurate measurement of performance presents difficult experimental problems at these low thrust levels; such problems require the development of special

impulse-, thrust-, and flow-measurement techniques. The mechanics and performance of very small nozzles require additional research to identify optimum nozzle configurations for use with flows approaching the limits of the continuum regime.

1231. Thompson Ramo Wooldridge, Inc., Cleveland, Ohio, FAILURE MODE AND EFFECT ANALYSIS - REACTION CONTROL POWER COMPONENT, DYNASOAR NO. 1 by H. W. Beatty, Jr., February 1962, LP-4770-516-808950-08, AD-432 630 (Unclassified).

Not abstracted.

1232. Thompson Ramo Wooldridge, Inc., Cleveland, Ohio, REACTION CONTROL POWER COMPONENT RELIABILITY FAILURE RATE ANALYSIS, DYNASOAR by H. W. Beatty, Jr., Jr., TM-3245-93-516-808950-08, AD-432 645, (Unclassified).

Not abstracted.

1233. Tinling, B. E., WATER-VAPOR JETS FOR SPACECRAFT ATTITUDE CONTROL, Space/Aeronautics, Vol. 38, September 1962, p. 161.

Not abstracted.

1234. Tomaszek, E. P., ALL-MECHANICAL ACTUATOR FOR HIGH TEMPERATURES, Space/Aeronautics, Vol. 41, January 1964, p. 261.

Not abstracted.

1235. Toms, R. S. H. and Kalensher, B. E., CONTROL OF A SYNCHRONOUS SATELLITE BY CONTINUOUS RADIAL THRUST, AIAA Journal, Vol. 2, July 1964, pp. 1179-1188.

Not abstracted.

1236. Traynelis, K. A.,
SECONDARY ROCKETS, Space/Aeronautics, Vol. 40, July 1963, pp. 141-143.

Not abstracted.

1237. Traynelis, K. A. and Ryan, D. L.,
HOT GAS CONTROL SYSTEMS; USING REACTION TO CONTROL VEHICLE ATTITUDE, Control Engineering, Vol. 8, July 1961, pp. 109-114.

Not abstracted.

1238. University of Illinois, Urbana, Illinois,
PHOTOMICROGRAPHY OF ELECTRICALLY SPRAYED HEAVY PARTICLES by C. D. Hendricks, R. S. Carson, J. J. Hogan, and J. M. Schneider, 1963, NSF-19776, AD-406 645, Contract AF-04(107)-63 (Unclassified).

Preliminary analysis of space flight trajectories has shown that electrostatic thrust devices using particles with charge-to-mass ratios in the range of 10^2 100,000 coulomb/kilogram would permit achievement of payload optimization quite readily. In addition, beam neutralization problems would be minimized. The research discussed is presently aimed at furthering the general knowledge of charged droplet production and behavior by studying the effects of such physical properties as density, viscosity, conductivity, and surface tension on the charge-to-mass ratio distribution. High speed photomicrographs of surface instabilities are presented and discussed and Rayleigh's theory on the instability of charged droplets is extended to include droplet emission.

1239. Vaeth, J. E.,
COMPATIBILITY OF IMPULSE MODULATION TECHNIQUES WITH ATTITUDE SENSOR NOISE AND SPACECRAFT MANEUVERING, IEEE Transaction on Automatic Control, Vol. AC-10, No. 1, January 1965, pp. 67-76.

Comparative evaluation is made of noise compatibility of three reaction jet-control techniques versus performance capabilities in spacecraft such as accuracy, fuel economy, and maneuver response rate; sensor design criteria and trade-offs defining allowable sensors and noise-filter parameters

are given; design guides for attitude control system synthesis are evolved from results of analog simulation of sensor noise and controller nonlinearities; design guides are applicable to sun and stellar observation, lunar reconnaissance, and photographic and radar surveillance from Earth satellites.

1240. No entry.

1241. Vaeth, J. E.,
VAPOR JET CONTROL OF SPACE VEHICLES, 1962 IRE International Convention Record, Part 2, Automatic Control, Circuit Theory, Vol. 10, pp. 194-204, A63-13581 (IRE International Convention, New York, New York, 26-29 March 1962).

Included is a description of a reaction-jet attitude-control technique which offers significant advantages in terms of accuracy, reliability, fuel economy, and operational flexibility. These advantages are realized by the use, in combination, of low-thrust vapor jets and time-dependent on-off switching circuits. The capabilities and limitations of this design approach are substantiated by an analog-computer program incorporating breadboard-switching circuits, and by vacuum-chamber testing of critical components. These technique and component developments are applicable to such space missions as astronomical observation, Earth reconnaissance, and stellar navigation. Design guides are presented for synthesizing a reaction-jet system to meet any particular set of performance specifications.

1242. Vickers, Inc., Research and Development Department, Troy, Michigan,
SOLID PROPELLANT ATTITUDE CONTROL SYSTEM, FINAL REPORT, SEPTEMBER 1960 - DECEMBER 1961 (U) by W. W. Chao, 13 April 1962, TM-NASA-M15, X63-12451, Contract NAS5-482 (Confidential).

Not abstracted.

1243. Westinghouse Electric Corporation, Air Arm Division, Baltimore, Maryland,
MAGNETIC TORQUERS FOR SPACE VEHICLE CONTROL, FINAL REPORT by J. Braumiller, G. E. Lynn, P. M. Julich, and G. W. Wood, January 1963, ASD-TDR-63-74, N63-14102, Contract AF-33(657)-8190 (Unclassified).

By controlling the currents in a group of three orthogonal coils fixed to the body of a satellite, a useful attitude-control torque can be produced by reaction with the Earth's magnetic field. Such magnetic torquing can take the form of direct control of the vehicle momentum or of indirect control by removing the momentum accumulated in reaction wheels. Magnetic actuators have been found to be a reliable and lightweight means of satellite torquing. As might be expected, limitations in torque capability, and therefore of accuracy, are experienced when magnetic actuators are used alone in a direct control system. Torquers with ferromagnetic cores are superior to air-cored coils from a weight standpoint, and are superior to permanent magnet devices from either a controllability or a reliability standpoint, depending on the complexity of the latter. Design equations have been evolved by means of which optimum iron-cored actuators may be mechanized, and these equations have been confirmed by tests of experimental torquers. Also, the Earth's magnetic field has been defined in terms of the coordinate axes of a vertically oriented satellite for a variety of orbits.

1244. Wright-Patterson Air Force Base, Ohio,
BASIC APPLIED RESEARCH IN FLUID POWER CONTROL, FOURTH PROGRESS REPORT, July 1963, ASD TDR-63-609, Contract AF-33(657)-7535 (Unclassified).

This report describes continuing applied research and development work on problems related to the design and development of high performance hydraulic and pneumatic control equipment for advanced aerospace systems. Sustained emphasis on pneumatic components and systems reflects a desired objective of employing gas power to operate systems which must function under a wide range of operating temperatures and/or in fields of high intensity radiation. Included in this report are descriptions of work on reaction jet servomotors, fluid jet modulators, and gas-lubricated bearings.

1245. Zimmerman, W. and Cox, R. M.,
GAS SERVOS FOR AEROSPACE CONTROL, Hydraulics and Pneumatics, Vol. 14, December 1961, pp. 78-80.

Not abstracted.

1246. Zoeckler, D. J.,
MERCURY CAPSULE REACTION CONTROL PROPULSION SYSTEM, Missiles and Space, October 1962, pp. 22-24, 56, and 58.

Covered in this article are: studies carried out for a method of space vehicle attitude control using forces developed by hydrogen peroxide thrust chambers; propellant characteristics and physical properties of 90 percent H_2O_2; details of reaction control propulsion pressure-fed system wherein regulated helium pressure applied to positive expulsion monopropellant tank supplies H_2O_2 to thrust chambers, where rapid decomposition occurs; subsystems involved; three basic operating modes which employ each subsystem independently or in combination; and results of the program.

AUTHOR INDEX

A

C

E

G

R

S

T

W

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* Redstone Scientific Information Center Research and Development Directorate U. S. Army Missile Command Redstone Arsenal, Alabama 35809	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP N/A

3. REPORT TITLE

SPACE VEHICLE NAVIGATION, GUIDANCE, AND CONTROL

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

State-of-the-art survey 1961 through 1966

5. AUTHOR(S) *(Last name, first name, initial)*

Langston, R.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
16 January 1967	500	12

8a. CONTRACT OR GRANT NO. N/A b. PROJECT NO. N/A c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) RSIC-611 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)* AD ______

10. AVAILABILITY/LIMITATION NOTICES

[redacted]

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
None	Same as No. 1

13. ABSTRACT

This report contains a summary of space vehicle guidance and control plus an extensive bibliography of the subject area. This report is intended to encompass only the interplanetary portion of the space vehicle flight. Launch vehicle guidance and control is covered in RSIC-494, entitled "Methods of Launch Vehicle Control." However, some fringe information in the area of orbital flight is included in the bibliography which may be applicable to interplanetary flight.

DD FORM 1 JAN 64 1473

UNCLASSIFIED

Security Classification

UNCLASSIFIED

Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Guidance of Interplanetary and Lunar Spacecraft						
Control of Interplanetary and Lunar Spacecraft						
Celestial Navigation of Interplanetary and Lunar Vehicles						
Optimization of Interplanetary Flight						
Attitude Stabilization of Space Vehicles						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization (*corporate author*) issuing the report.

2*a*. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2*b*. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all-capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7*a*. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7*b*. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8*a*. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8*b*, 8*c*, & 8*d*. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9*a*. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9*b*. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers (*either by the originator or by the sponsor*), also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through
_______________________________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through
_______________________________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through
_______________________________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring (*paying for*) the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as (*TS*), (*S*), (*C*), or (*U*).

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.

UNCLASSIFIED

Security Classification